TUBE CAD JOURNAL

This Issue

Another issue, and a fat one at that. Amazing. This journal's future may be uncertain, but this issue moves forward. Have you ever noticed how difficult it is to read a schematic with a white background, particularly on a computer screen? The contrast is too great. Hence the gray backgrounds for this issue's schematics. Feedback is encouraged. Is it more readable? Do you like it? Does it print as well?

Hybrid amplifiers, comprising vacuum tube and solid-state, are covered in this issue. (Even those readers who will not touch a solid-state diode should read this article, as the topologies are often directly transferable to pure tube OTL amplifiers.) We look at several topologies and try to weigh the advantages and liabilities of each. With the astronomical prices of new 300Bs and high quality output transformers, it behooves us to examine a cheaper means of delivering vacuum tube glory to a loudspeaker. But do not believe that miserliness is our only motive; potentially, the hybrid amplifier may prove the winner against the pure-tube or the unalloyed solid-state amplifier, just as the hybrid car may win against the electric car and the internal combustion car.

Tube mixers get a treatment in this issue. I know from the many e-mails that building a tube microphone preamp / tube mixer is on many readers short list of desired topics. Here is some help.

Remember, if you have a request or suggestion of your own for either an article topic or circuit explanation, please e-mail:

Editor

In This Issue

Hybrid Amplifiers

The promise made is that the palpability and sweetness of tubes can be added to the power and slam of solid-state. Or at least that is what the advertising copy claims. (Ever notice how often a solid-state amplifier is proudly described as sounding tube-like? Yet have you ever read of a tube amplifier being proudly described as sounding solid-state-like?) While some good hybrid amplifiers exist, too many sound like bad compromises, often laden with noise, dark tonalities, and poor bass definition, and even sometimes stricken with gritty highs. What went wrong? How was it possible to lose the attributes and retain the faults of both technologies?

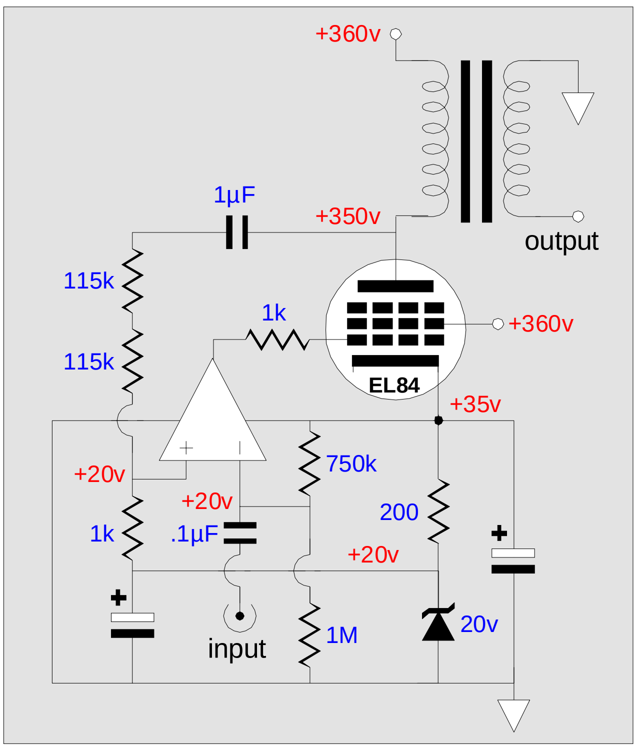
Sometimes the blame rests with the designer who is only fluent in one technology. Such a designer may competently assemble only half of the amplifier. Their designs are easy to spot, as circuits are only half understood. Half the circuit is original and the other half is lifted from old schematics. For example, the output stage from the schematic of a mediocre MOSFET amplifier is shotgun wedded to clever tube front-end; or an excessively retro tube input stage is lifted from a RCA tube manual design example or an old Western Electric schematic, which then cascades into a slick solid-state output stage that includes an opto-isolated auto-bias circuit.

Most of the time, the blame rests in the real goal of the amplifier: a marketable dirt cheap amplifier with some of the tube's cachet. Tubes are added to promote sales, not sonics, as all the other design choices are subservient to cost. Here the tube is but an expensive LED replacement. Such amplifiers well deserve the "hybrid" name which shares its etymological root with the word "hubris;" when a wild boar mated with a domestic sow, the offspring was an *outrage*, a *hybrid*. On the other hand, if the entire design is given careful and inspired consideration, and if cost savings are not valued more than sonics, a good hybrid amplifier is certainly possible, as we have all heard pure tube and solid-state designs that sound good. Our task then is to make a happy wedding.

Ultimately, what we desire is an amplifier that is as quiet and as bass solid as the best solid-state amplifiers and as fluid and as lifelike as the best tube amplifiers.

Which Way? T>SS or SS>T?

While most tube hybrid amplifiers hold a tube front-end driving a solid-state output stage, the inverse is certainly possible, i.e. solid-state devices driving a tube output stage. Audio Research and Stax have made such amplifiers (as, I am sure, have many music amplifier companies, as it is the tube output stage's softer clipping that pleases the professional musician and it is the cheap IC front-ends that please the accountants).



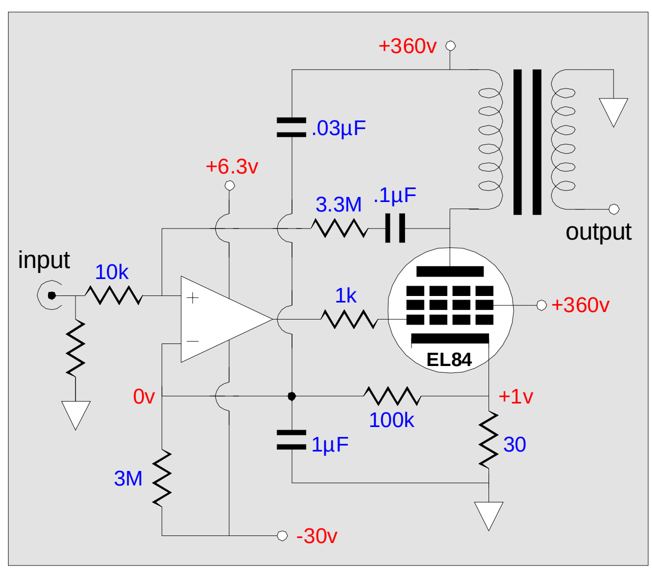
Self powered hybrid IC front-end
single-ended amplifier with auto-bias

The amplifier shown above uses an IC to provide the gain necessary to drive the EL84 to full output and to set the EL84's idle current. The Op-Amp strives to equalize the voltages on its inputs. Thus the Op-Amp will automatically adjust the output tube's idle current until the voltage divider (formed by the 1 meg and 750k resistors) yields the same voltage as the zener develops. (The quiescent current through the IC must be included in the calculation. Fortunately, most Op-Amps draw little current.)

The IC's power supply is created by the current draw through the cathode resistor and zener, which might result in the IC latch-up at turn-on. This problem can be often solved by adding input protection diodes to the IC or by simply using a different IC.

The problem with connecting a feedback loop to the plate is that the signal at the plate is not necessarily the same signal that will leave the transformer! For example, if no signal is present at the input, the feedback used will force the plate to mimic the ground's lack of signal. The power supply, however, contains a noise voltage that will couple through the transformer to the output, as the noise then becomes a signal. But if the plate held the same amount of noise (in the same phase) as the power supply, then the transformer would not see any difference to relay to the secondary.

The circuit below hopes to overcome the power supply noise. It uses a separate negative power supply rail and the DC heater power supply voltage to power the Op-Amplifier. A small fraction of power supply noise is injected at the positive input (the tube inverts the phase) to develop that noise at the plate. Thus, the inclusion of the .03µF capacitor. This capacitor along with the 1µF capacitor defines a voltage divider. The ratio of this diver is made to match that of the ratio of feedback resistors. Therefore, we have by injecting noise into the amplifier lowered the noise at the output: not Zen, but Aikido applied to electronics.

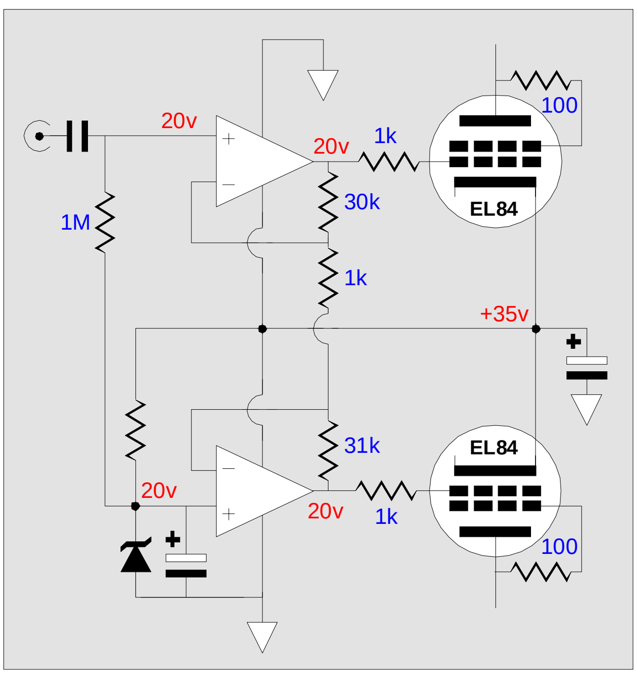


Hybrid IC front-end single-ended
amplifier with power supply noise cancellation

The 30 volts across the 3 meg resistor defines a constant current that must be offset by a positive voltage across the 100k resistor sufficient to match that current. Thus, the 3 meg resistor and the 30 ohm cathode resistor set the idle current through the output tube. Bear in mind that this circuit does not wrap the feedback loop across the entire amplifier. The output transformer is out of the loop and thus its distortions will not be ironed out, which is unfortunate in that no transformer is perfect, but fortuitous in that the feedback mechanism is free of the phase anomalies that the transformer brings to the mix. In other words, the amplifier is much more stable in this configuration. The tube, however, is in the feedback loop and its distortions will be reduced.

Using the positive input of the Op-Amp is not a mistake: the entire amplifier functions in the inverting mode, as the output tube inverts the signal, making the entire amplifier inverting.

Converting this topology to push-pull is not easy without using many more ICs or coupling capacitors. But a simple push-pull amplifier can be made from two EL84s and a dual Op-Amplifier. The circuit below does not include the tubes in the feedback loop and thus the EL84s are run in triode mode to lower the distortion and output impedance. Like the first circuit the Op-Amp finds its power supply from the cathode biasing, but does not apply an auto-bias.

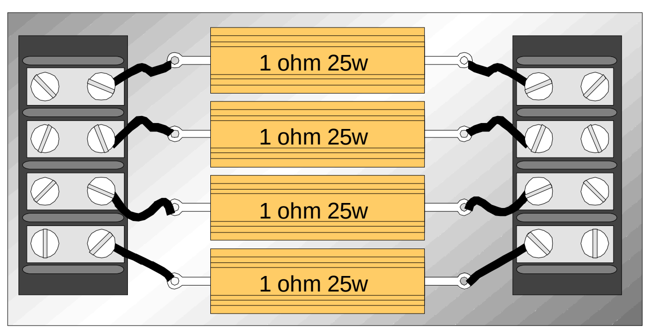


Hybrid IC front-end single-ended amplifier without global feedback loop

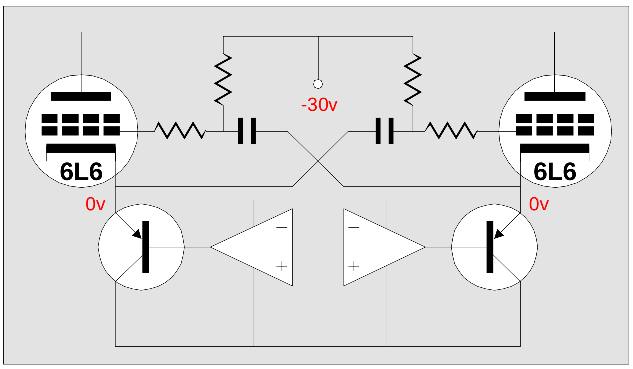
These two Op-Amps accomplishes the signal phase inversion and the balanced drive signal. The second Op-Amp works as both as a phase splitter and as a driver for the second output tube. The first Op-Amp is configured as a non-inverting amplifier with a gain of 31. In contrast, the second Op-Amp is configured as a inverting amplifier with also a gain of 31.

A third circuit possibility is to use only current feedback from the output stage. The circuit below includes the output tubes in its feedback loop, but only in terms of current. In other words, the output impedance of this amplifier will be extremely high, as the amplifier defines a current source rather than a voltage source. This will un-tune many bass reflex loudspeakers, as the speaker will only find its own resistance shunting its extraneous movements. But if the speaker has a truly flat impedance curve as some of the planer and ribbon speakers do, the high output impedance will not matter.

An EE friend who claimed that he knew why tube amplifiers sound better than solid-state amplifiers made an experiment to prove it. He argued that the higher output impedance of tube amplifiers actually helped the speaker. He bolted four 1 ohm power resistors to an aluminum plate and the resistors attached to two terminal blocks. This arrangement was then inserted in between his solid-state amplifier and his speakers. Effectively, the solid-state amplifier's damping factor fell to 4, as the added 2 ohms of resistance swamped out the .05 ohms output impedance of the amplifier. How did it sound? On his speakers it improved the sound. While it was still too mechanical sounding, it did have a warmer and more relaxed sound with an improved stereo image. I am not sure what was going on. Maybe the resistors isolated the amplifier from the airborne electromagnetic radiation we live in. or maybe it shielded the amplifier from the reactive kickbacks from the crossover. Or maybe, most speakers do need to see a higher impedance from the amplifier.



One important note is that both the single-ended and the push-pull circuits that use auto-bias must run the output tubes in strict Class-A mode. The Op-Amps will strive to maintain a constant average current flow through the output tubes and only the Class-A amplifier draws a constant average current flow. A second note is that this circuit will not work with tubes like the 6L6 or 6V6. These tubes require a much larger grid voltage swing. In order to use these tubes, an Op-Amp which can withstand a higher power supply voltage differential will be needed along with an increased negative power supply voltage. An alternative approach might be to use the lower voltage ICs in a cross-coupled configuration.



Cross-coupling effectively doubles voltage swing

Beyond auto-biasing, a further advantage that a solid-state front-end holds over the vacuum state equivalent is less noise. While a power amplifier is not as noise sensitive as a phono preamp, lowering the noise floor can only help make the qualities of the output stage more apparent. Simple thermal noise can be overcome by paralleling many tubes; microphonics can be lessened slightly by isolating the tubes from the chassis and by damping the envelopes, but microphonics is only really eliminated by finding low microphonic tubes, which is not easy. Double mica spacers are certainly a move in the right direction as are steel clamping-clips internal to tubes such as in the 5751. Still, vacuum tubes too much resemble tuning forks in construction: one end fixed, the other end free to resonate. DC power supplies for the heaters also help. But ultimately, the solid-state device wins. So why not use the solid-state device for those small fragile signals until they can be passed on to a tube? A single FET input stage perhaps? I understand that even Jean Hiagra uses a solid-state pre-pre-preamp (this datum is for the benefit of those who insist on designer labels).

The Usual Way: T>SS

The common approach is use tubes for voltage gain and MOSFETs or transistors for current gain. This arrangement appeals to our sense of fairness: tubes are happiest with voltage and woefully current limited; solid-state devices are current ebullient but fearful of over voltages. An exaggeration this, but not without a kernel of truth. Surely, you have read the advertising copy: the Mega X837 can put out peaks of 100 amperes! As its power supply holds 40 volt rails, the implication is that it can put out 2000 RMS watts. It can't, unless you have a .4 ohm speaker. 100 amperes is of little importance for those own 16 ohm speakers, which can only see a peak current of 2.5A into 40 volts (i.e. 50 watts into 16 ohms). This situation finds a complement in the ad copy for some tube OTL amplifiers: The Ultra-Mega Blue Swan puts out voltage peaks of 140 volts. Impressive, but of little importance to those who own 4 ohm speakers, a load that runs into the amplifier's 2A maximum continuous current output limit all too often (8 watts into 4 ohms).

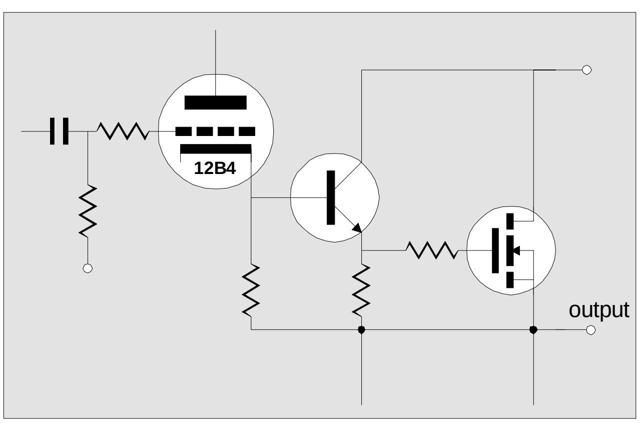
(If you are thinking that the world needs a good 1 ohm and a good 100 ohm speaker, you are right. A compromise might be to make loudspeaker drivers that held four independent voice coil windings each with an 8 ohm impedance. All four windings wired in parallel gives a final impedance of 2 ohms; all wired in series, 32 ohms; and all placed in a series-parallel combination, 8 ohms.)

Transistor or MOSFET or IGBT?

Which solid-state device should be used in the output stage? The transistor wins in theory, but the MOSFET wins in practice is the quick answer. The transistor has a much greater transconductance which makes for a greater gain, which in turn allows for more feedback, which ultimately lowers more distortion. Yet, the MOSFET is used in most professional, high-power amplifiers because the MOSFET does not blowout as readily as the transistor does. Furthermore, the MOSFET is almost always used in hybrid designs due to its reputation for being more tube like in sonic character and because its gate represents a high impedance that is theoretically easier to drive than the transistor's base. (I do not think that MOSFETs amplifiers sound anything like a 2A3 or even a triode connected pentode like the EL34. And I find its high gate capacitance a true nuisance.)

But we can like the MOSFET's comparative ease of biasing and the negative temperature coefficient of the best MOSFETs, i.e. the lateral MOSFETs once made by Hitachi and now made by Magnatek and others. Here is where MOSFETs show a clear advantage over the transistors, as biasing difficulties and smoking output stages limit ones enthusiasm for the transistor.

When correctly biased, a comparable transistor amplifier will exhibit a lower distortion figure than a comparable MOSFET amplifier. But herein lies the rub: virtually all transistor output stages are run in a lean Class-B and thus the transistor output stage is extremely sensitive to incorrect biasing. Too little or too much bias current will lead to increased distortion. So while it is easier to produce a lower distortion transistor amplifier, it is more difficult to maintain its low distortion. The MOSFET, on the other hand, is less sensitive to shifts in the bias voltages, as it has a much lower transconductance. Furthermore, MOSFET output stages always require a much higher quiescent idle current, which increases the percentage of Class-A operation in Class-AB mix, which is all for the good, as the first watt of power is sonically the most important watt. Add to these benefits the advantage of virtually no thermal runaway, and the MOSFET appears to be the clear winner. But if the output stage operates in a pure Class-A mode, then the transistor may prove a better choice, as a DC servo loop can maintain both the correct bias voltages and work to slow down runaways. Or if sufficient emitter resistance is added to effectively lower the transistor's transconductance to the level of a MOSFET, the transistor will certainly be more linear. (I would love to build an amplifier that used all three devices in parallel in the output stage: tube, MOSFET, and bipolar transistor.)



What about IGBTs? Are they worth using? *No* is the quick answer. For the amplifier designer, these devices encompass the worst of both technologies: MOSFET and transistor, but then they were not designed with audio in mind. The sad fact is that very few active devices were actually designed with audio in mind. The 300B and the 12AY7 were. As were the Hitachi lateral MOSFETS. But most discrete electronic devices whether tube or solid-state were designed for power supply, computer, motor, or radio use. Audio must live on the crumbs that fall off the technology table.

The Greedy and the Puritanical

One trap we should avoid is greed. Virtually every commercially made amplifier is optimized for power output. I have seen excellent 32 watt amplifiers ruined because the output wattage had to be increased to 40 watts to make the marketing department happy. In spite of the our new energy shortage (I live in California), in spite of the vestigial puritanical outlook that all Americans suffer from (even the most extravagant rakehells are burdened with a puritanical overlay), in spite of the universal masculine urge to maximize power (who wouldn't want 10 watts instead of 7 watts), I have learned to let go of potential wattage. To use a food analogy, which is better: a small serving of the most delicious dish in the world or a serving twice as large but only half as tasty? (If you did not choose the first choice, I do not understand why you are reading this journal.) Triodes with their large unusable spans of plate voltage are inefficient. Chokes, voltage regulators, and cathode biasing with their voltage drops rob potential watts. Class-A operation is anything but inefficient and current source loaded Class-A operation even less so. Yet, all of these add to a better sound. (My good friend, Glenn, is so convinced by experience that the inefficient sounds best that he is constantly on the outlook for ways to lower his amplifier's efficiency.)

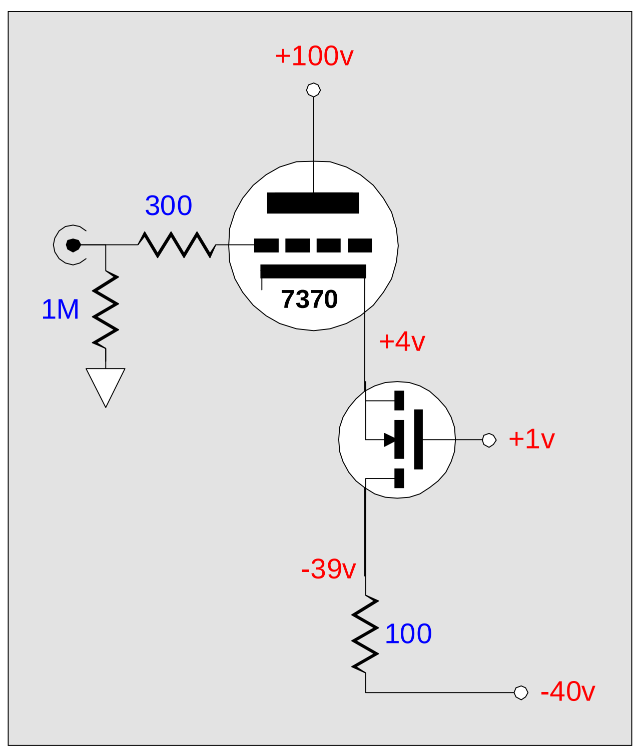
So if we used 2 ohm emitter resistors rather than the usual .1 ohm resistors or if we used chokes in solid-state portion of the power supply, we would certainly lose many potential watts, but we might gain a much better sounding amplifier. Neither the energy conscious, nor the puritanical, nor the inferiority complex ridden who have 400 watt amplifiers in their cars, none will be happy with the diminished wattage, only your ears will be.

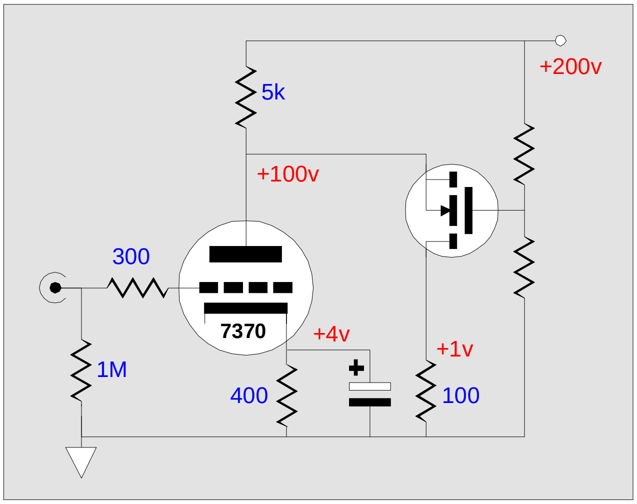
Of course, if you design your hybrid amplifier for the best sound rather than for the highest efficiency, you should at least turnoff the lights and the refrigerator. (If not for energy conservation, then at least for better enjoyment of the music.)

Inverted cascode

One real advantage solid-state devices enjoy over the vacuum tube lies in having a “P” version of the FET, MOSFET, and transistor. Tube electronics would immeasurably benefit from a P version of the triode and pentode. In other words, a tube whose cathode received electrons from its plate. Such a tube is impossible, sadly. But by using P solid-state devices we can come up with topologies that would be impossible with just tubes.

The circuit below uses only one triode and is DC coupled. In function it is a cascode circuit. The triode is locked between the B+ connection and the MOSFET's source. As far as the triode is concerned its cathode and plate cannot move up or down. But its grid can. As the triode sees a varying grid voltage, the current conduction through the triode will vary in response. The varying of current through the 100 ohm resistor defines a varying voltage, which is in phase with the input, as the both the resistor and tube share the same current path. Roughly, the gain is equal the triode's Gm against the resistor's value.



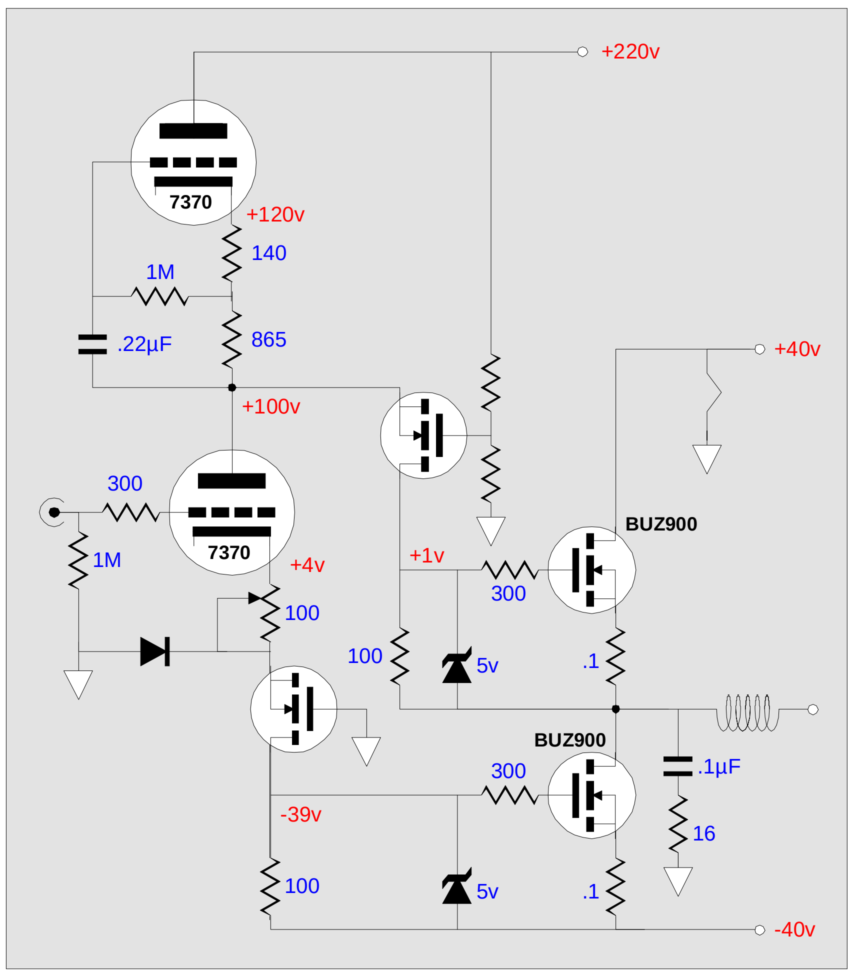


The circuit shown above is also a cascode design. The bottom triode's cathode-to-plate voltage is locked by the MOSFET's source. (The plate resistor could be replaced with a top triode configured as a current source to decreased power supply noise making it way to the output.)

Any signal presented to the bottom triode's grid will provoke a current variation through the triode, which cannot find a exit path through the plate resistor, as the MOSFET holds a fixed voltage across the plate resistor, which in turn, fixes the current through the resistor. So where do the current variations go? Through the MOSFET and then into the 100 ohm resistor is the only path. What happens is that the MOSFET's source moves ever so slightly in response to these variations (the MOSFET has huge amount of transconductance compared to the triode) and this movement results in a varying current through the MOSFET. If the triode were pulled from its socket, the MOSFET's idle current would double, but the voltage across the 5k resistor would barely change. Locking the plate voltage is the main point of a cascode circuit. In fact, his circuit functions much like the previous one save for the phase inversion at the top of the 100 ohm resistor.

Adding both circuits together allows us to create a fully DC coupled hybrid amplifier. The amplifier shown below illustrates what is possible. The current variations through the input tube drives both output MOSFETs. So as not to confuse too many readers, no feedback loop is shown, but one could easily be added by bridging the bottom triode's grid to the amplifier's output. And a DC servo-loop can be added to the bottom MOSFET's gate, which would eliminate any DC offsets and the need for the potentiometer at the bottom triode's cathode.

The 5 volt zeners protect the MOSFETs from too great a current draw in the case of a shorted output. The 7370 is a 40 volt heater version of the 5687, which allows attaching the heater across one leg of the power supply. The BUZ900 might not be the best choice, as a greater gain could be realized by replacing the 100 ohm resistors with 400 ohm resistors. But the relatively low gate threshold voltage (usually an advantage) of this device prohibits using the higher value resistors.



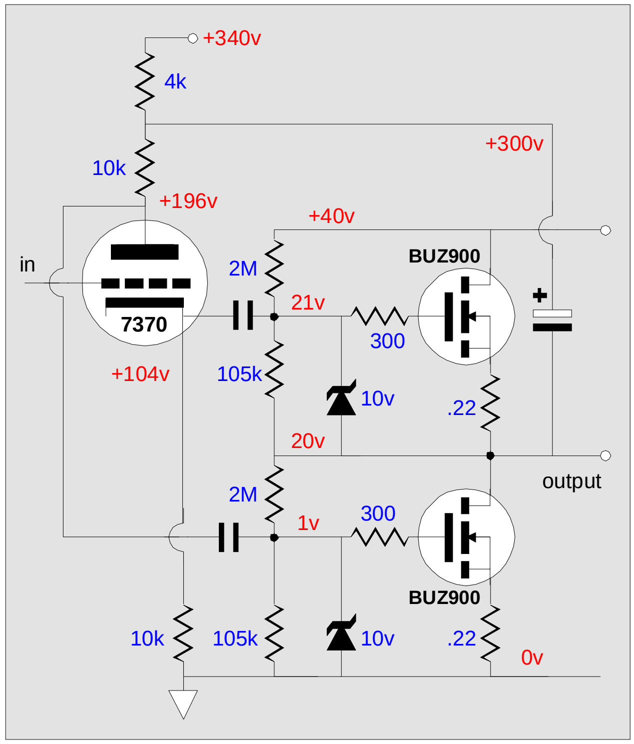
The Symmetrical and the Non-Symmetrical

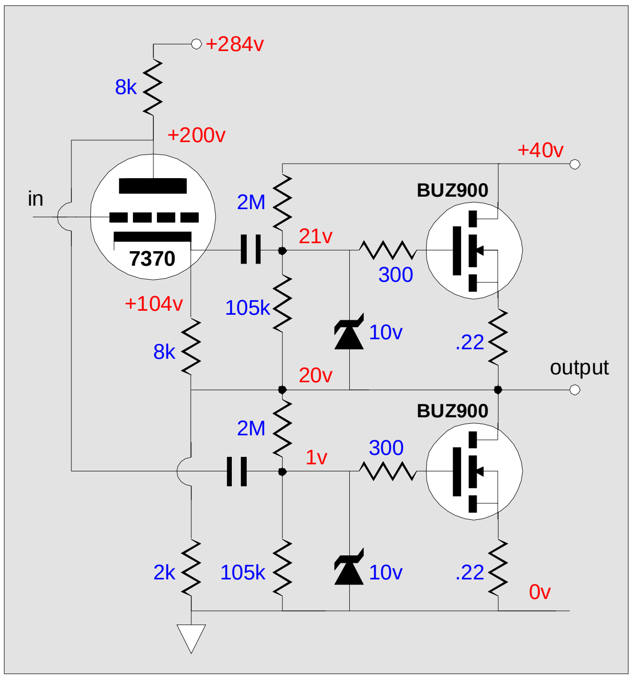
Note that in the previous circuit both MOSFETs are of N-channel flavor. This will upset many, as they have been raised on symmetrical solid-state output stages. Yet, there are many advantages to not going symmetrical. While a few N-channel MOSFETs have P-channel equivalents, the match is seldom that good. The transconductances differ as do the input capacitances. I understand that when Hitachi made their famous complementary MOSFETs, they started by making the best Plate-channel MOSFET they could and then they crippled a N-channel MOSFET until it matched it. On the other hand, inexpensive N-channel MOSFETs from the same run will match each other at least in transconductance and capacitance. And matching is not that difficult, requiring only a low voltage source, a voltage meter, a few resistors and a potentiometer. The disadvantage to using only one type of MOSFET is that we must ensure that both are treated equally, i.e. that both see an identical gate-to-source voltage and that power supply noise relations are fully understood.

In this amplifier, the top and bottom MOSFET are being used in exactly the same way: as grounded source amplifiers. The top MOSFET may look as if it is used in a source follower configuration, but it is not, as the 100 ohm resistor is attached to the output. In other words, the top MOSFET offers no output resistance, as the gate will follow the source's movements. For example, +1 volt pulse applied to the output will force the 100 ohm resistor up 1 volt, which the source will dutifully follow. On the other hand, if the 100 ohm terminated into ground and not the output, then that same pulse would force the top MOSFET to stop conducting altogether, as its gate would move effectively –1 volts relative to its source. The output impedance in this case will equal the inverse of the transconductance of the top MOSFET. And of course, the bottom MOSFET offers no resistance to the output's voltage movement, as its gate is entirely immune to any voltage movements at the output.

Adding a feedback loop is what will lower the output impedance and gain of the amplifier. With the feedback loop in place, the same pulse will force the input tube to conduct more current, which will impose a negative pulse at the top MOSFET's gate and a positive pulse at the bottom MOSFET's gate.

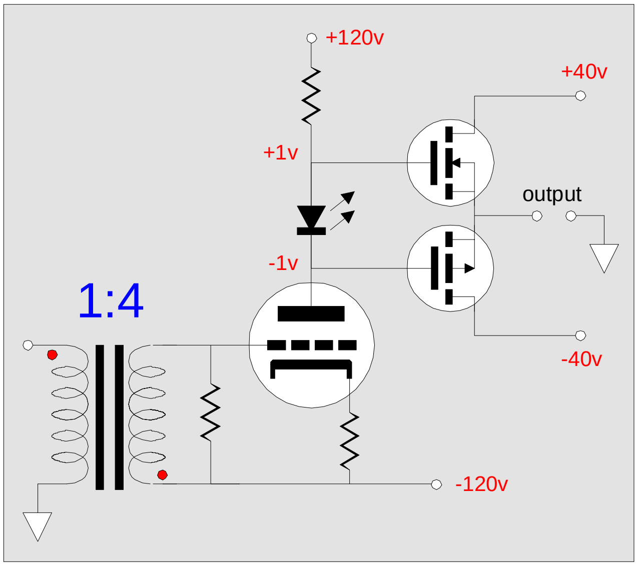
In a different topology, the same two MOSFETs can be used as source followers that offer a low output impedance and no gain, as in the two circuits below. In both circuits, a +1 volt pulse will be bucked by the top MOSFET's gate not moving and by the bottom MOSFET's gate seeing a +1 volt pulse. The output impedance for both circuits is half the inverse of the transconductance of the MOSFET.





Symmetrical Output Stages

In spite of a truly complementary set of MOSFETs, the symmetrical output stage is the standard. This is easy enough to understand: two symmetrical source followers working into the same load. It can be run in Class-A, AB, B and it can be driven from a single phase. This last point constitutes a major feature for many, as phase splitters confuse most beginners. Furthermore, a supremely simple amplifier has its charms. For example, all that is needed is one triode, two MOSFETs, and one interstage transformer as is shown below.



Simplest hybrid amplifier possible?

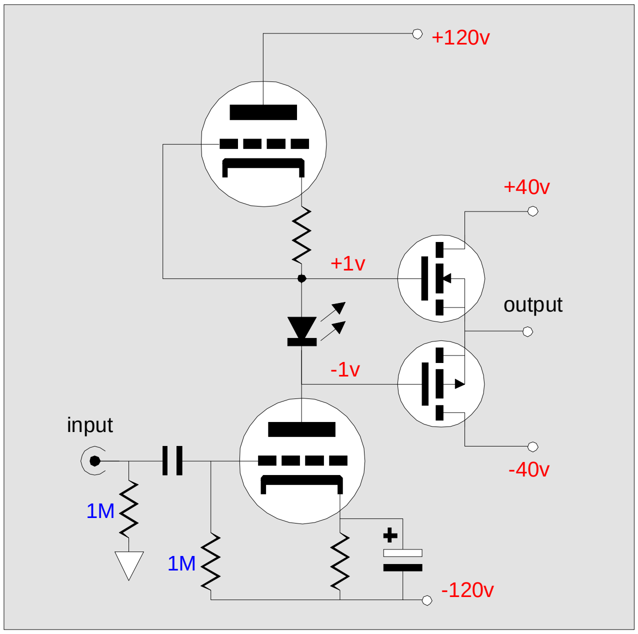
While many bells and whistles are required, such as grid and gate stopper resistors, fuses, LED bypass capacitor, gate protection zeners, and source resistors, the amplifier is actually functional as is and could be described as the world's simplest hybrid. The amplifier does not even invert the output signal phase, as the input transformer inverts the phase for us. To make a truly useable amplifier, a bit more complexity is demanded.

One obvious danger with this existing topology is that at turn-on the tube is not yet conducting and the gates will see +120 volts. Replacing the plate resistor with another triode configured as a current source will help a bit, as both tubes will heat up in unison.

Another problem area is the lack of a DC offset nulling control. The simplest solution is to add a potentiometer to half of the circuit so that the output can be brought to zero volts. The slicker and safer approach is to use a DC servo to steer the output stage to zero volts.

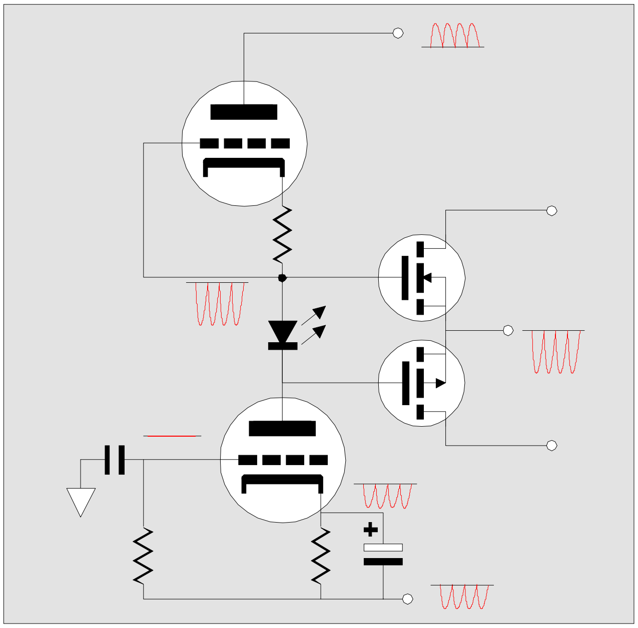
Many will balk at the use of an input transformer. Wasn't the great advantage to solid-state amplifier that they eliminate the need for signal carrying transformers? Yet, a good transformer solves as many problems as it creates. The operative word in the last sentence was "good." Good transformers are both expensive and hard to find. The obvious solution is to replace the transformer with a coupling capacitor. (DC coupling is impossible, as the bottom triode's grid is –120 volts below ground level.)

The amplifier below is a simplification of a design sent from David S., a reader wishing to build the simplest hybrid possible. (A similar circuit appeared in a mid-80s *MJ Stereo Technic* article by Sidewinder.) It use a coupling capacitor to block the huge voltage offset between the input and the bottom triode's grid.

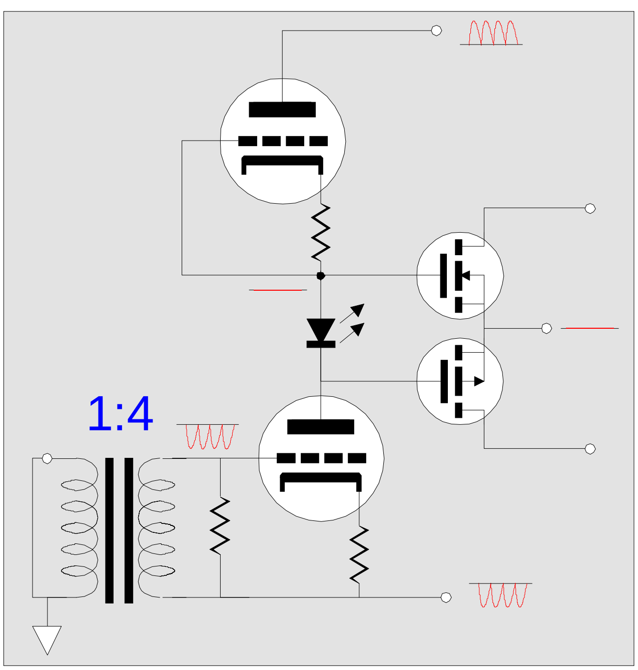


Capacitor coupled simplest hybrid amplifier

With the coupling capacitor comes a problem. I am sure that many of you have caught on to how passionately I hate noise. So naturally, that is the first aspect I look at in an amplifier's design. The bottom triode has two inputs the first obviously is the grid, the second is cathode. Grounding the input makes this clearer. The grid sees the ground's zero noise voltage while the cathode sees the full negative power supply rail noise voltage. This noise is then amplified in-phase at the plate. Now, if this amplifier used a great deal of negative feedback, the true source of the noise at the output might not be found. But with a zero feedback amplifier, less is hidden.

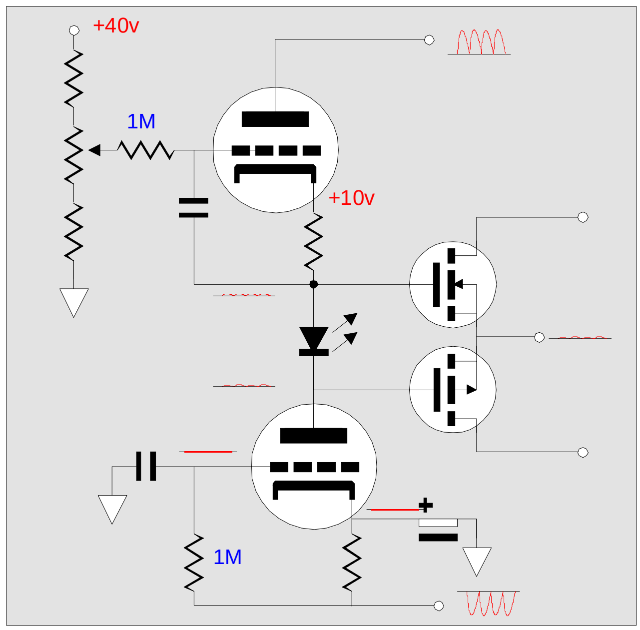


Once again, getting rid of this noise can be handled rather nicely by using a coupling transformer instead of the coupling capacitor. Now, the bottom triode's grid and cathode both see the same power supply noise, which prevents the noise's amplification. The triode will experience a varying current flow in response to that noise, but then so to will the top triode and in equal degree. The result is a cancellation of positive and negative power supply noise into a blissful null at the center point where the MOSFETs meet and the speaker attaches.



Of course, the same questions always comes up when any audio transformer is considered: where to find a good sample and how much will it cost? Several companies have come out with high quality interstage transformers that could be pressed into use. And the telecommunication industry might provide a ready source as well. Still this transformer is bound to be expensive. An alternative plan is to retain the coupling capacitor, but alter the bottom triode's cathode resistor bypassing scheme.

The circuit below retains the coupling capacitor, but uses a different bypassing arrangement for the cathode resistor. The bypass capacitor's polarity has been reversed and it is now terminated into ground, rather than the negative power supply rail.

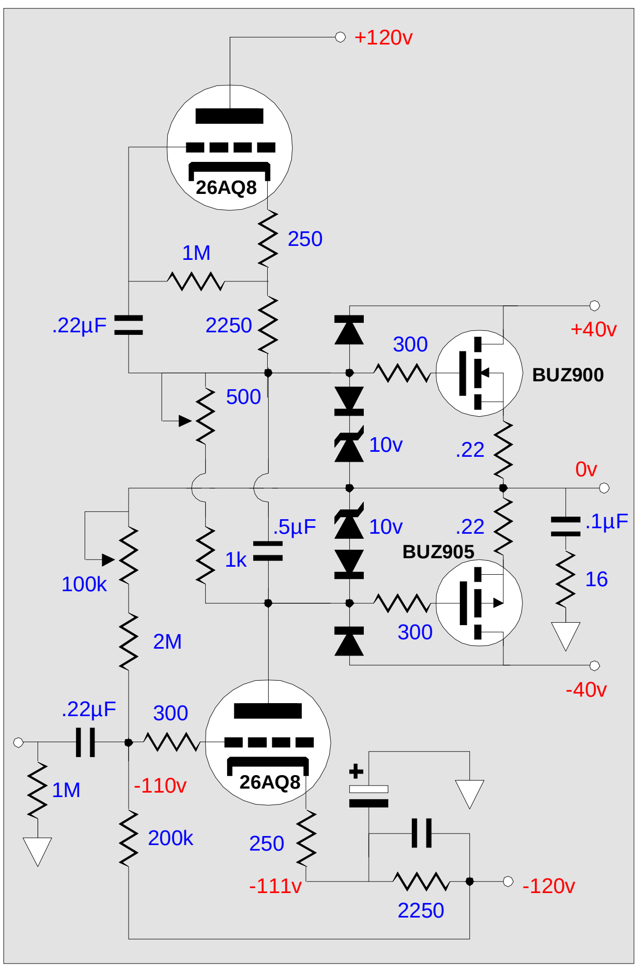


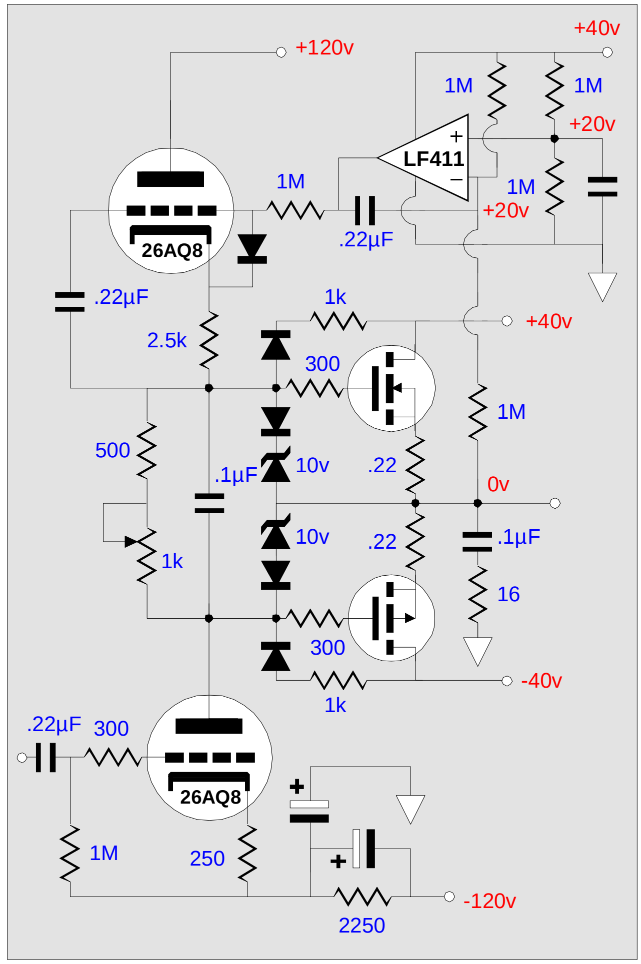
The no longer simplest hybrid amplifier

This change will force the cathode to mimic the ground's lack of signal rather than the power supply rail's noise. Thus the bottom triode's grid and cathode will track each other much better. The top triode's topology has become a bit more complex, but with the reward of a higher impedance for the bottom triode to work into (more gain, less distortion and noise) and a ready means of compensating for the DC offset, which otherwise could as high as 5 volts! While the noise is lowered substantially, it is not altogether nulled. Adding a small capacitor across the bottom triode's cathode resistor will purposely inject a small amount of noise to offset the small amount from the top power supply rail.

Adding this extra detail and a few others together into one circuit yields something not so elegant as David's original circuit. The circuit below uses potentiometers to set the idle current and DC offset. The following circuit uses a DC servo that loops around the output to the top triode's grid to maintain an automatically low DC offset. The added diode that spans between the grid and cathode of the top triode serves to provide a DC path for the servo even if the driver tube is removed from the circuit.

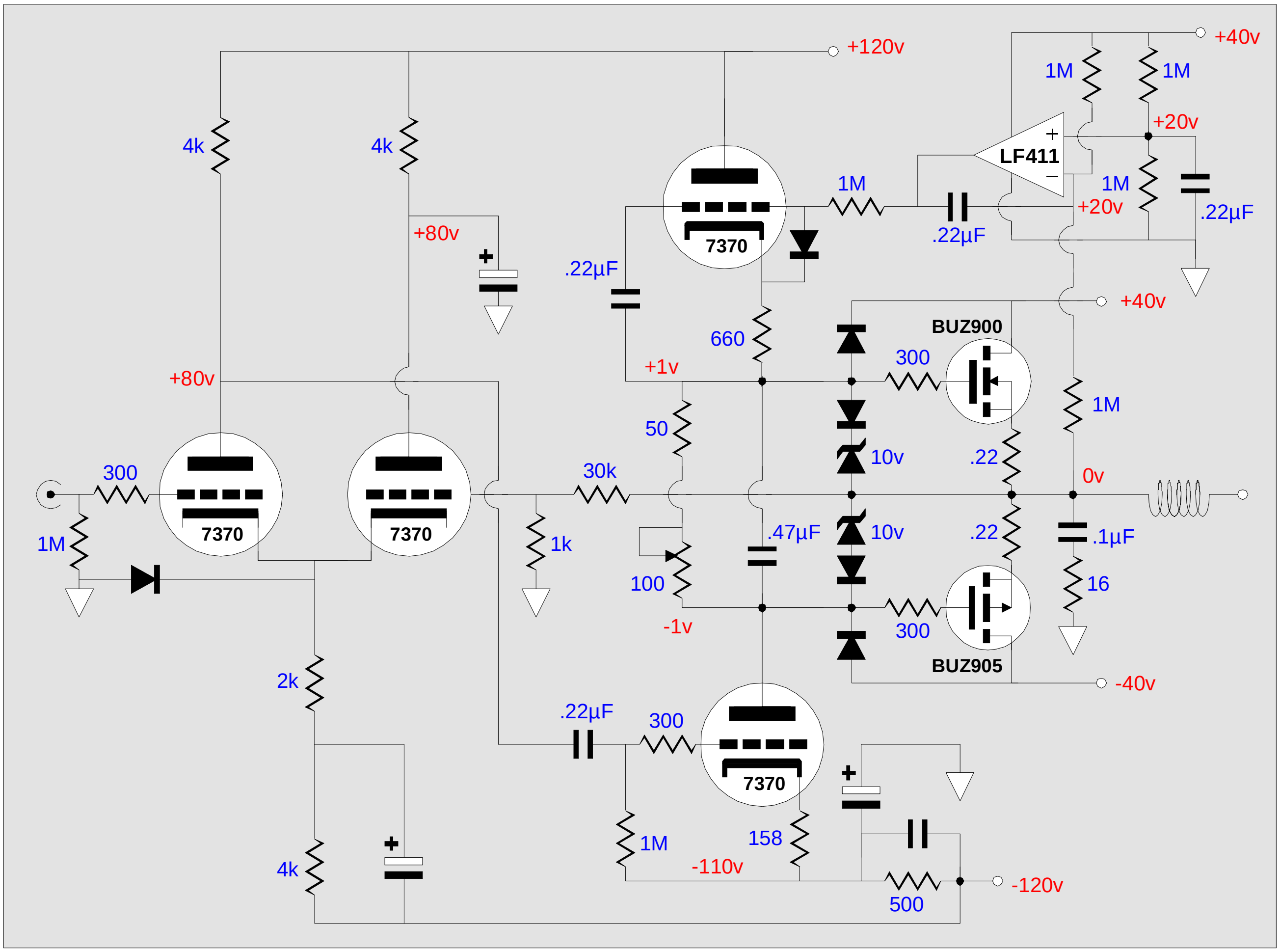
In both circuits, the two zeners are added to protect the MOSFET output stage form excessive current draws and damaging input voltage spikes. The diodes bridging the gates to drains severe the same purpose in the absence of a load. The bias LED has been replaced by the resistor and potentiometer combination to ease idle current adjustments. The top triode's cathode resistor value has been upped to increase its effective impedance. The 26AQ8 is used to increase the gain for the those running passive line stages (at the risk of insufficient charging current).



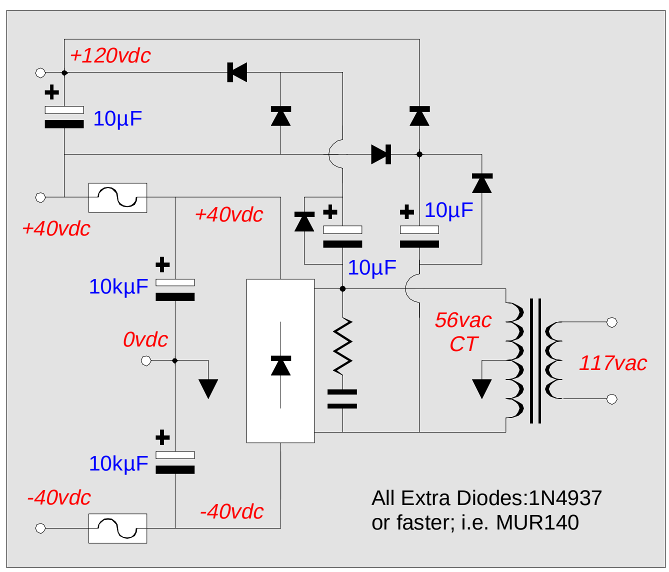


The 26AQ8 is the same as the 6AQ8 with a different heater voltage and current rating. Both tubes are undervalued in audio applications. The 26AQ8's 26 volt heater voltage is only 14 volts shy of the rail voltages, which could be achieved by using a series resistor to drop the 14 volts. Because of the large voltage differential between the top and bottom triodes, the DC referencing of the heater is critical. Optimally in this circuit, the heater power supply should be reference to about –50 volts, which would split the difference between the cathodes. Attaching one end of the 26AQ8's heater to the –40 volt power supply rail is close to optimal. (The voltage dropping resistor would then attach to the other end of the heater and ground.)

One possible problem is the inability of the 26AQ8 to draw sufficient current to quickly charge the large input capacitance of the MOSFETs. Overcoming this potential problem will require using a different tube. The obvious choice is the one made by David, the 7370.



The one failing of the 7370, however, is its low mu (17) which results in a potential gain no larger than 17 for the stage. In other words, the burden of increased gain will be shifted to the previous piece of equipment, as it will have to supply at least 3 volts of output swing to drive the hybrid amplifier to full output. For an active preamp this will not be hard; for the passive line stage, impossible, as some inputs only provide half a volt of signal. Consequently, more gain is needed. Using the same 7370 tube in a modified common cathode configuration, the output is taken at the added triode's plate. This circuit is more linear than the simple grounded cathode amplifier, as its cathode resistor is effectively the other triode's rp divided by its mu. In other words, it uses the other triode's nonlinearity to cancel much of its own nonlinearity. Like the grounded cathode amplifier, it does invert the phase at its plate, which will make the entire amplifier non-phase inverting. And feedback (about 10 dB) is taken at the second triode's grid.



Above is the power supply for the amplifier. The high voltage are derived from the low voltage windings by using voltage doubler circuits.

The *Tube CAD Journal* signature noise canceling technique of using a partially bypassed cathode resistor for the first stage is implemented. The potentiometer allows for idle current adjustment, which can be read from the voltage drop across the .22 ohm resistors. The LF411 Op-Amp works to reduce the DC offset at the output. All in all, we have moved quite a bit from the world's simplest hybrid amplifier.

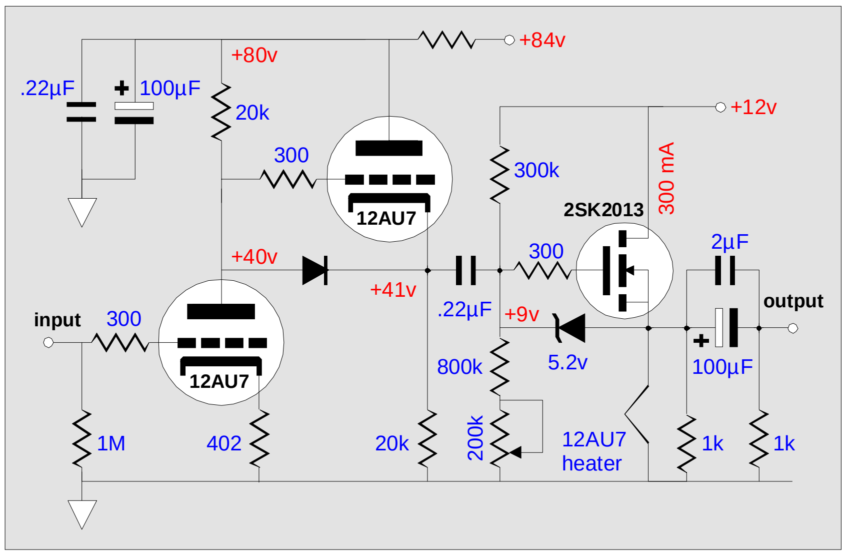
Simple Hybrid Headphone Amplifier

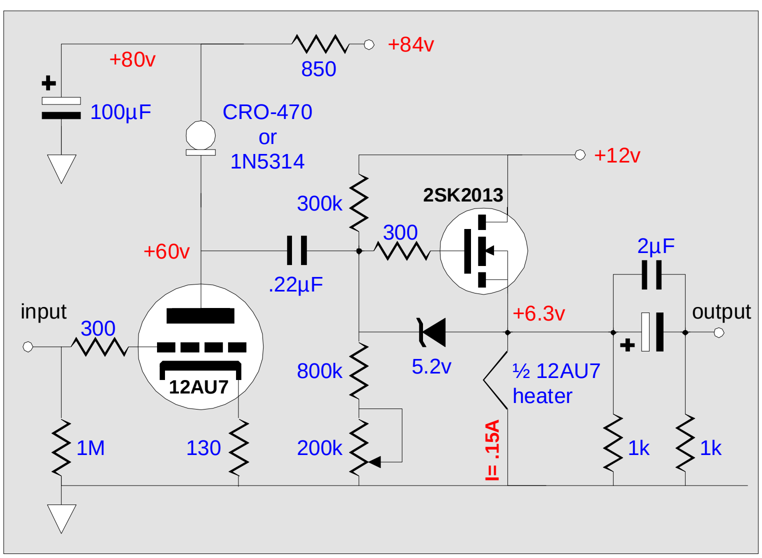
The following circuits do not really follow the previous thread other than illustrate simple designs. The first circuit was born out of a desire to come up with a portable tube headphone amplifier.

The MOSFET chosen for this application is a true sleeper. The 2SK2013 is a very linear power MOSFET with a truly useable negative temperature coefficient. However, it is not destined to become popular because of its paltry 25 watt dissipation limit. Remember the food choice. Well, when choosing solid-state devices, twice the food of half the quality always wins. The 2SK1530 with its 150 watt dissipation limit, will find a thousandfold greater use. Yet it is a much poorer choice in terms of audio purity.

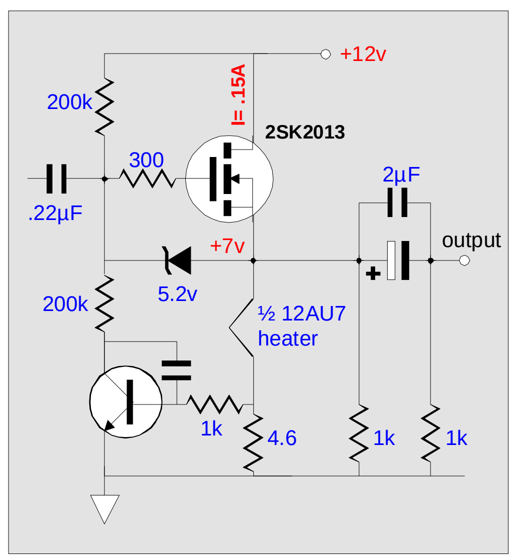
Here is where the tube fans have it all over their solid-state brethren. Tube fanciers are happy to live with the 3 watts that a miserly 2A3 gives us in a single-ended amplifier...but what a nice 3 watts.

This headphone amplifier does not use the 12AU7 to its best advantage, as it current starves the 12AU7. The second version uses a FET current source to both reduce the noise at the output and to increase the idle current. The cathode follower is eliminated and, like the previous circuit, it uses the 12AU7's heater element as the load for the output MOSFET. The potentiometer sets the idle current. If an auto-bias is desired, the last circuit should prove helpful. The base-to-emitter voltage drop is used as a voltage reference, which the transistor uses to compare against the voltage across 4.6 resistor.





Improved simple hybrid headphone amplifier



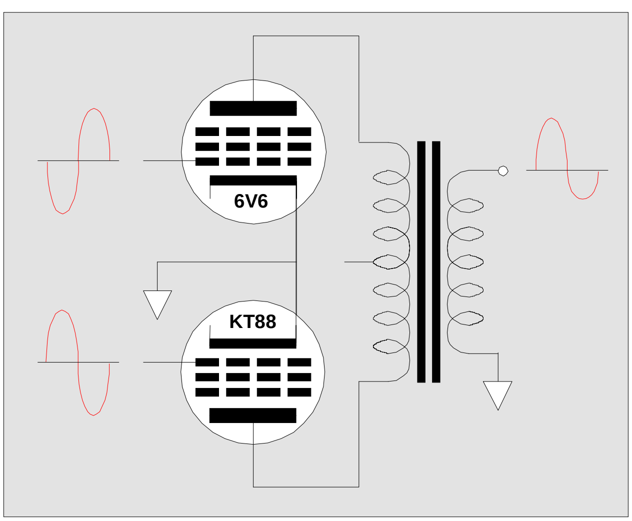
Auto-bias hybrid headphone amplifier

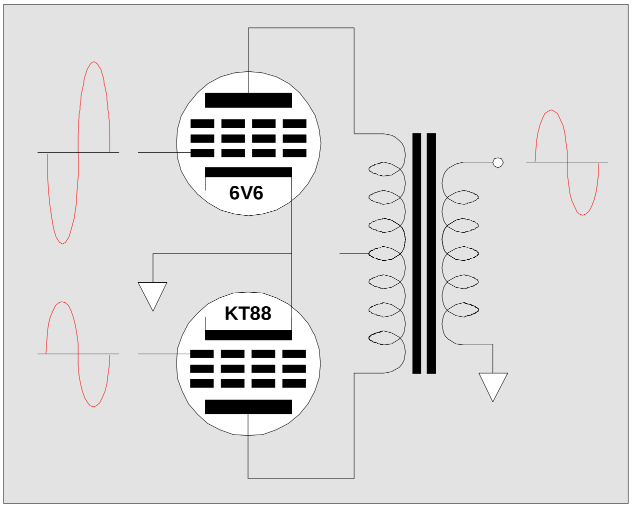
Six Basic OTL Topologies

If you choose to use identical output stage devices, whether they be NPN transistors, N-channel MOSFETs, triodes, or pentodes, then there are only six ready ways to equalize the drive voltages to the devices in an OTL push-pull amplifier. Of course, there are an infinite possible embellishments on these fundamental topologies. However, seeing the same basic pattern in a multitude of particular circuits is the basis of understand electronics.

Some can't. the mystic refuses to generalize: grass is not seen, but a million individuated living plants regale his eyes. Many, if not most, audiophiles believe that changing a coupling capacitor's brand results in creating a wholly new topology. This failure (or refusal) to generalize is laudable in the viewing other people, but laughable in the attempting to understand how an amplifier works.

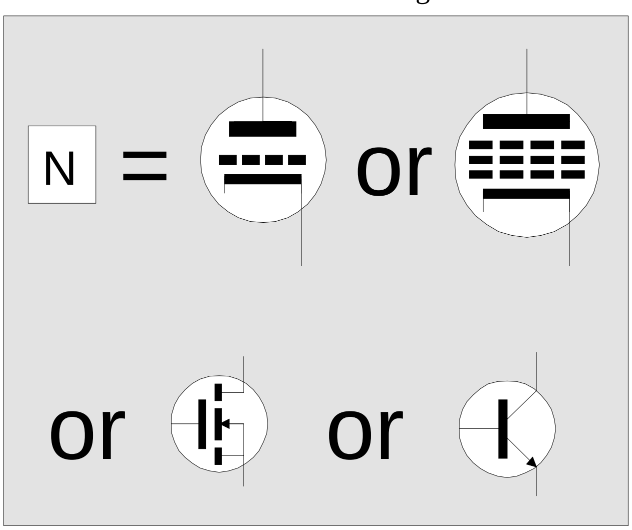
Of course, this begs the question: why would we want to equalize the drive voltages to the output devices? The answer is simple: we do not want a grossly distorted output, which is the result of an unbalanced drive. A key point here is that *a balanced input signal does not necessarily achieve a balanced drive for the output stage*. (To make this point, let's stick with conventional transformer coupled push-pull amplifiers for now.) For example, if dissimilar output tubes are used, say a 6V6 and KT88, then a perfectly balanced signal would result in a distorted output, as these very unmatched output tubes require a differing grid voltage swing to develop a balanced plate swing. In other words, the only time we need a perfectly balanced input signal is when we are using perfectly balanced output tubes in a perfectly matched configuration.



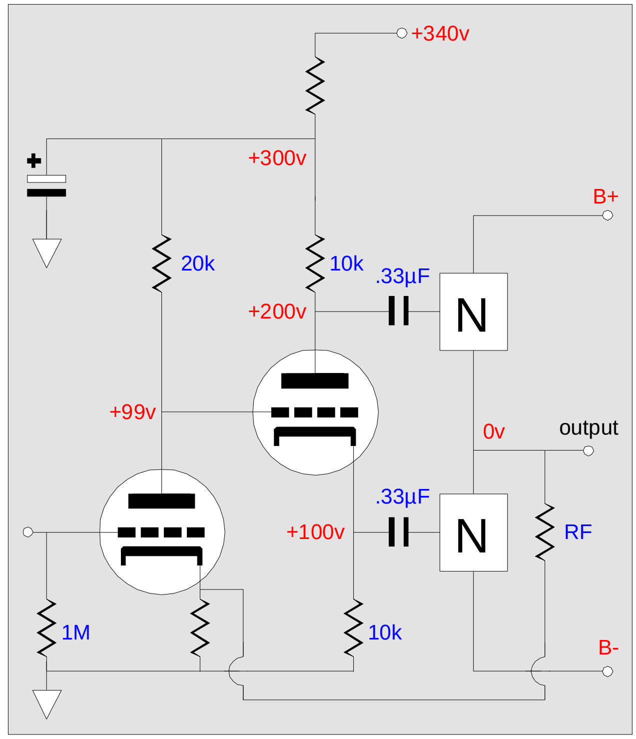


Now let's return to OTL push-pull output stages. The devices can be perfectly matched, but unless each receives the appropriate grid voltage swings, the output will be distorted. In turn, the appropriate grid voltage swing is dependent on the load being driven and few loads have a consistent impedance cross the audio band. I am stressing this point because many commercially successful amplifiers have been designed in complete ignorance or misunderstanding of it. And since tube audio design is not taught in schools anymore, most tube fanciers use schematics as textbooks. (You can imagine what happens when the textbook has a typo in it as many do). So, if you wish to understand both OTL and hybrid circuits, you must understand how the output devices must work equally, i.e. complementarily to deliver an undistorted output voltage into the loudspeaker.

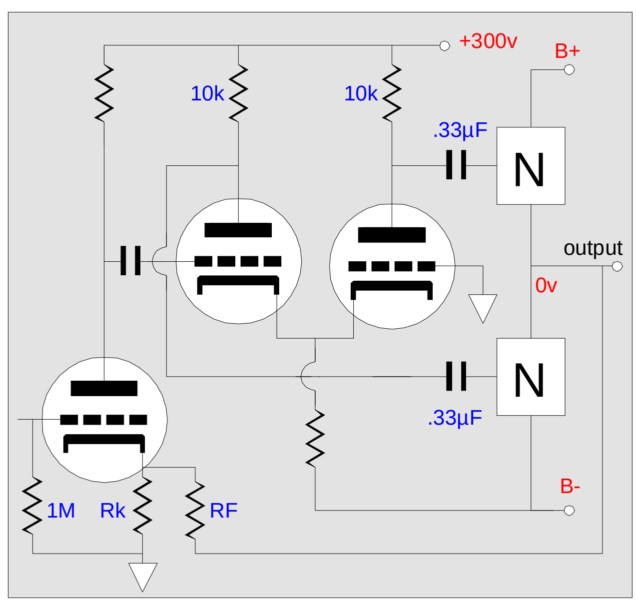
Since the OTL or hybrid output stage can use either tubes or solid-state devices, a block with "N" in it will be used in all the following circuits.



Below are two circuits designed in ignorance of the need for an appropriate balanced drive signal for each output device. Variations on these circuits are common, but all share the mistake of ignoring that the top output device effective drive voltage is altered by the influence the output voltage across load impedance makes. In other words, output signal effects the drive signals.



Bad design 1 with unbalanced drive circuit



Bad design 2 with unbalanced drive circuit

If these circuits are so poorly conceived, why do they persist? The answer requires only one word: feedback. Feedback irons out the distortion caused by the unbalanced drive: the greater the feedback ratio, the less the distortion.

Interestingly enough, under one special circumstance, both circuits will fall into a balanced drive state: when the output is shorted to ground. In this case, the top and bottom output devices will see a balanced drive signal. But for any impedance other than zero ohms, the circuits will be see an unbalanced drive for the output stage. For example, if the output device has 1 amp/volt transconductance figure and the load impedance is 8 ohms and the output stage in run in Class-B, then a +10 volt pulse is applied to the top device's input, the output will swing 8.888 volts positively. On the other hand, if a +10 volt pulse is applied to the bottom device's input, the output will swing 17.777 volts negatively. Why the asymmetry? When the top device saw the +10 volt pulse, the bottom device was completely turned off, which means that the current flowing through the load and the top device must match, as these two define only one current path. The current flowing through the load is given by:

Iload = Vo / Rload.

Where Vo is the output voltage swing. The current through the top device is given by:

Itop = (Vin - Vo)Gm.

Where Vin is the drive voltage. The current flowing through the bottom device is given by:

Ibot = Iload + Itop.

The positive output voltage swing is given by:

Vo = RloadVinGm / (1 + RloadGm).

Where Vin equals the drive voltage. The negative output voltage swing is given by:

Vo = 2RloadVinGm / (1 + RloadGm).

Obviously, these two formulas differ by a factor of 2.

Restoring a balanced drive would seem easy enough: just provide twice the signal voltage to the top device as is provided to the bottom device. And in a pure Class-B amplifier this ratio works; but in a Class-AB amplifier, the bias current will skew the ratio. Furthermore, even in the Class-B amplifier, this fixed ratio is still suboptimal. For example, as the load approaches zero ohms, the top device will needlessly dissipate twice the wattage as the bottom device: a +2 volt pulse to the top device's input results in 2 amps of current conduction, but a +1 volt pulse results in only 1 amp of current conduction.

In a pure Class-A amplifier this fixed ratio leads to a strange state. Normally, a push-pull Class-A amplifier's idle current equals one half of its peak output current swing. And when the load equals infinity, the idle current remains constant. But when we force a fixed 2:1 ratio, the amplifier will cease to draw any idle current when input signal swings negatively enough to cutoff the bottom device. Conversely, when input signal swings positively the bottom device's increased current conduction forces the amplifier dissipation to at least double (and this happens in the absence of a load).

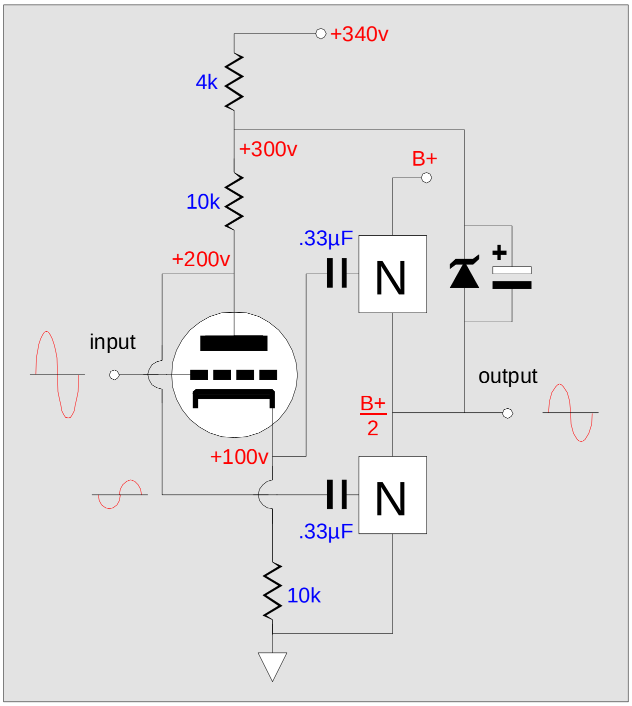
Feedback saves the day for this poorly designed amplifier. The feedback resistors are themselves a load for the output stage. And the feedback senses the lopsided behavior and attempts to correct it. Break the feedback loop, however, and the distortion becomes apparent. An analogy might be having a car that veers to the right when driven on a flat road. So rather than fix the poor geometry of the front-end, you replace the tires on the right side of the car with a larger pair. Now the car drive straight on flat road, but on a inclined road it veers once again. And on it a winding road it takes all your concentration and strength not to crash your car. This will not do. The only solution (other than gobs of feedback) is to dynamically create an equalizing drive voltage for the top and bottom devices while they are working into any load impedance in any class of operation. Julius Futterman understood this requirement and all of his OTL amplifiers include dynamic drive equalization. True, the Futterman amplifiers also used a huge amount of feedback. But in his amplifiers the feedback wasn't used up equalizing the drive signals. Instead, it was used to lower the noise, the distortion, and the output impedance of the amplifiers.

Most importantly, dynamically equalizing the drive voltage for the top and bottom devices allows us to build low and even feedback free designs, designs that do not need feedback's heavy hand to steer the amplifier out of distortion.

Of the possible six push-pull nonsymmetrical output stage topologies only half will work with a feedback free design. These topologies arrange the both output devices to function in a follower mode by returning 100% of the output to the output device's inputs. In other words, these topologies realize 100% degenerative feedback just as a cathode follower or source follower or emitter follower does.

100% Feedback
No Gain Output Stages

The following circuits ensure that both output devices see 100% of the output returned to their inputs. In all of these circuits, the top devices merely sees a ground referenced input signal; the bottom devices, a output referenced input signal.



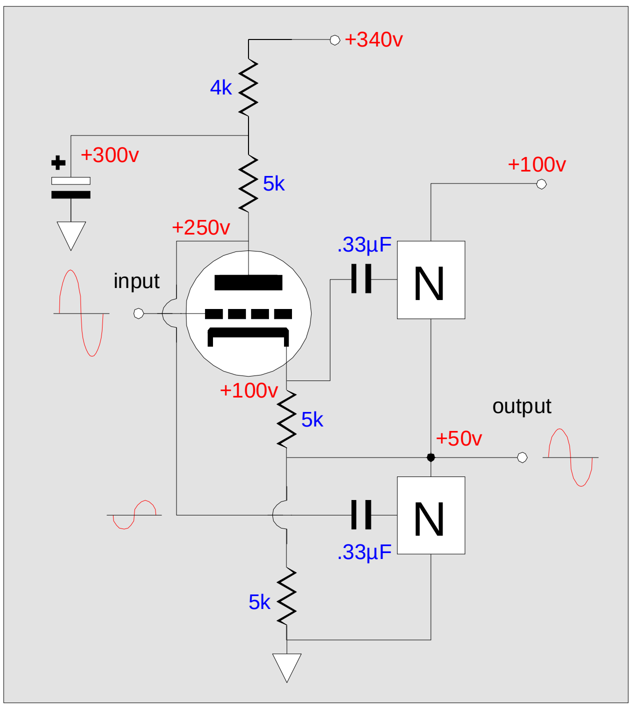
In the above circuit, the split-load phase splitter feeds the input signal to the top device in phase but slightly attenuated. The plate inverts the signal for the bottom device. The zener diode-capacitor combination provides the dynamic equalizing mechanism. But first, let's consider the static case. For example, if the output is shorted to ground, the drive signals presented to both output devices will exactly equal each other, as the phase splitter's plate and cathode resistor match and the zener only works maintain a fixed voltage for the top of the plate resistor. Consequently, any input signal will produce an equal positive and negative peak current swing into the ground, as bottom output devices see the same magnitude of input signal. If the output is forced up by +1 volt, the top device will decrease its conduction by its transconductance against the effectively –1 volt input signal. Complementarily, the bottom device will increase its conduction by its gm against +1 volts, as the zener-capacitor combination will relay the pulse to the top of the plate resistor.

Any disturbance at the top of the plate resistor transfers to the plate below, as the triode's plate resistance is greatly magnified by the large valued unbypassed cathode resistor. This relayed pulse is then relayed once again by the coupling capacitor to the bottom device's input, which will provoke an increase in current conduction equal to the pulse's voltage against the transconductance of the bottom device. So effectively, the output impedance of circuit (in Class-A) is equal to inverse of twice the transconductance of the output devices used.

(Some readers are thinking that since the effective rp of the phase splitter's triode is not infinite, there must be some attenuation of the pulse's magnitude, which means that the drive balance cannot be perfect between output devices. And these reader are right, but only about the slight attenuation of the pulse. But since the effective rp is not infinite also means that the phase splitter's cathode must climb slightly in response to a higher plate voltage and this slight increase decreases the magnitude of the pulse to the top device. In other words, a balanced drive is obtained.)

When the load is greater than zero, this zener will work to equalize the drive voltages between top and bottom devices. For example, with an 8 ohm load, the top device will realizes some percentage of its input signal into this load, which is then relayed to the top of the phase splitter's plate resistor, subtracting from the inverted signal already developed there, yielding an equal drive voltage for the bottom device. The resulting reduced signal is then given to the bottom device's input. Once again, but in greater detail: let's say our output stage is running with an idle current of 0 amps (Class-B) and it sees an 8 ohm load. A +11 volt pulse is applied to the phase splitter's input but only +10 volts appears at the cathode, as a 6BX7 was used. This +10 pulse further reduces to +8 volts into the 8 ohm load. Now 8 ohms into 8 volts equals 1 amp of current, which means that the effective transconductance of just the top device is 500 mA per volt, as it took 2 volts (10 volts – 8 volts) to develop the 1 A into the load. The bottom device was already turned off, so the negative 2 volt pulse (-10 volts - 8 volts) it saw at its input could not provoke any further decrease in current conduction. If the idle current had been 2 amps, the input voltage would have been +10 volts, as both devices would contribute to the output; the top device would increase 500 mA and the bottom device would decrease 500 mA in conduction.

In the circuit below, the same aims as the pervious circuit are achieved by different means. This time the equalization mechanism is found at the cathode end of the phase splitter. Once again the output works as a push-pull follower that does not invert the phase of the input signal nor does it provide any gain. The top device still sees the ground referenced signal and the bottom device sees the output referenced signal. The zener-capacitor combination is not needed, as the output DC couples to the bottom of the cathode resistor.

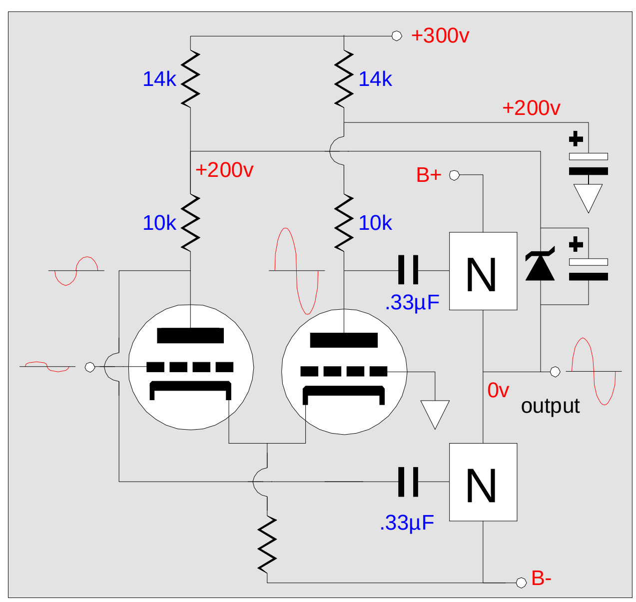


Let's start with a grounded output (I always try both zero and infinity when I evaluate an amplifier, as I assume that if an amplifier can work into these two extremes, then it can work into any resistance.) Since we have grounded the output, the circuit reduces to a split-load phase splitter feeding two grounded plate or drain or collector followers. The drive signal balance is ensured by the equal valued plate and cathode resistors. Like the previous circuit, the output impedance is equal to the reciprocal of the transconductance of the output device, when only one device conducts (Class-B); and half that value when both conduct (Class-A). This is shown by applying a +1 volt pulse to the output. The top device sees this pulse as a +1 volt negative pulse at its input, as the pulse forces the output device's grid or gate or base negative relative to its cathode or source or emitter.

The +1 Volt pulse also decreases the voltage across the cathode resistor, which in turn decreases the current through this resistor, which will also decrease the current flowing through the plate resistor, as both are in the same current path. Since the top of the plate resistor is fixed and cannot move the plate must move up one volt to make up for the one volt loss across the plate resistor. This means that the pulse applied to the output is relayed to the bottom output device via the coupling capacitor. Upon seeing the positive pulse, the bottom device will increase its conduction; thus bucking the positive going pulse. A negative going pulse provokes a negative pulse at the plate, which serves to decrease the bottom output device's conduction.

When the output is terminated into an 8 ohm load, the output's connection to the bottom of the cathode resistor provides the equalizing drive for the bottom output device. To whatever degree the output voltage lags behind the top output device's input voltage is the degree that the output voltage will subtract from the raw drive voltage to the bottom output device. For example, if 21 volts of drive is needed to bring the output to +20 volts of output, then the top output device sees only +1 volt out of the +21 volts presented to its input. The bottom output device sees its raw –21 volts input signal being reduced by the +20 volts output voltage to only –1 volts.

In the circuit below, the a differential amplifier provides voltage gain, while the output devices still function as unity gain followers. Both the bottom and top output devices receive the same magnitude drive voltages, which the zener-capacitor provides.



Starting with a grounded output, the circuit reduces to a long-tail phase splitter feeding two grounded plate or drain or collector followers. The drive signal balance is ensured by the equal valued plate resistors. (Actually, the second plate resistor should be larger, as even an infinitely large cathode resistor will not result in an equal gain from the two plates.)

Like the previous circuits, the output impedance is equal to the reciprocal of the transconductance of the output device, when only one output device conducts (Class-B); and half that value when both conduct (Class-A). This is shown by applying a +1 volt pulse to the output. The top output device sees this pulse as a 1 volt negative pulse at its input and the bottom output device sees the pulse as a 1 volt positive pulse at its input, as the zener-capacitor combination relays the pulse to the top of the first plate resistor, which in turn is relayed to the bottom of the resistor and from there travels to input of the bottom output device. When the output works into an 8 ohm loan, the zener-capacitor combination allows for dynamic equalization of the drive for the bottom output device.

In comparison with the split-load based circuits, this circuit's phase splitter offers gain. In other words, this last circuit can stand on its own as a complete amplifier. While some further design choices are needed, such as which triodes to use, high mu or high current, this circuit will perform well as drawn. Improving the circuit is as easy as replacing the cathode resistor with a current source, which not only improves the balance, it improves the PSRR of the amplifier. If the second triode's grid is used as a feedback port, then the current source is even more beneficial. Consider the extreme case wherein all of the output signal is fed back. In this case, the entire amplifier becomes a unity gain buffer. What comes in should come out. Thus, the first triode's grid and the second triode's grid will see the same signal in terms of phase and magnitude. Were only a cathode resistor used, the input signal would be imposed on it. For example, if the input signal consists of a +10 volt pulse, a 10k cathode resistor would see an increase of 1 mA in current conduction. This increase will have to be shared by both plate resistors, which will result in both output voltages being forced more negative than they should be. Conversely, if the input signal consists of a -10 volt pulse, the cathode resistor would see an decrease of 1 mA in current conduction.

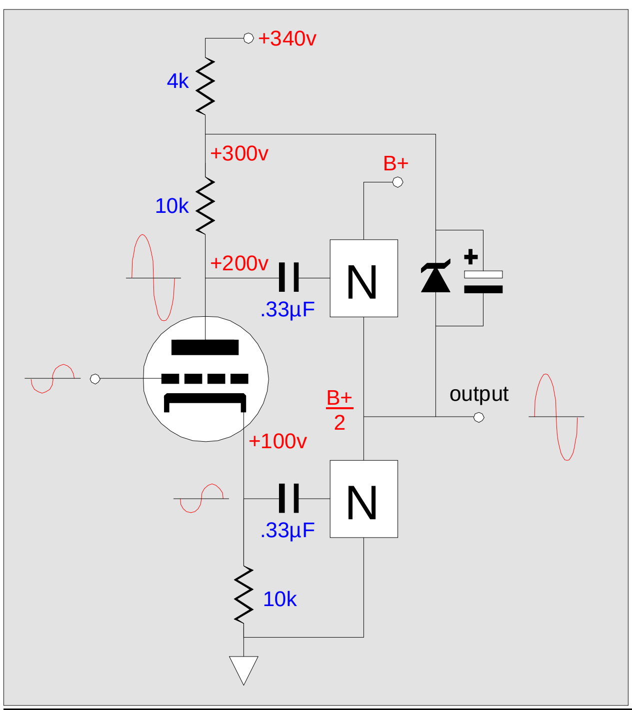
This decrease in current will result in both output voltages being forced more positive than they should be. These unwanted fluctuations in drive voltages create unwanted current fluctuations through the output devices that cancel in a Class-A amplifier but are released to the output in a Class-AB, B amplifier. The current source maintains a constant current draw and effectively eliminates this distortion mechanism.

(Class-A does more than just provide a more linear transfer curve, it allows a push-pull amplifier to actually cancel both common mode noises and distortions. Unfortunately, amplifier noise is only measured with a shorted input. Consequently, the Class-AB amplifier real noise contribution is not measured, but certainly heard.)

100% Potential Gain Realization

We have covered three of the common circuits used to equalize the drive voltages to the identical output devices in an OTL push-pull amplifier. These three circuits shared a low output impedance unity gain follower output stage. The next three circuits have output stage that provides gain, but not a low output impedances or a low distortion figure. Consequently, these circuit demand a feedback loop to reign in the output stage.

The circuit below uses the split-load phase splitter to drive the two output devices. The output is phase inverted. The gain is roughly equal to output device's Gm against load in a Class-B amplifier.

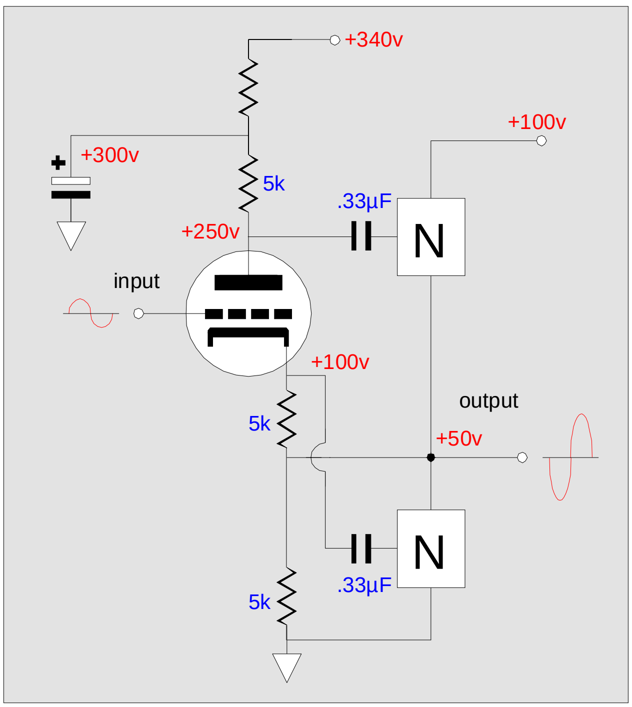


In a Class-A amplifier, the gain is roughly equal to twice the output device's Gm against load. The zener-capacitor combination strives to eliminate the follower like action the top output device's placement seems to imply and thus it works to increase the gain and output impedance of the device. Shorting the output, reveals that both output devices work evenly in drawing and sourcing current from the grounded output, as both devices must see an identical magnitude input signal. Forcing the output +1 volts up cannot force the bottom device to see the +1 volt pulse at its input, as there is no mechanism to relay the pulse. Nor can the top output device see the pulse, as the zener-capacitor combination pulls the plate resistor voltages up by the same +1 volts.

Feedback can be applied by adding two resistors to this circuit: one entering the grid and one spanning the grid to the output. With this feedback loop in place, a positive pulse applied to the output will be fed back to the grid, which will relay it in phase to the bottom output device and out of phase to the top output device. The bottom device will conduct more and the top device will conduct less, both of which will buck the pulse. However, this simple feedback based amplifier works best with high transconductance output devices. Tubes (and to a certain extant MOSFETs) require an additional gain stage. Adding a simple grounded cathode amplifier is the obvious choice when using MOSFETs. When using tubes for the output stage, the better choice is two triodes in cascade or two in a cascode configuration or single pentode based grounded cathode stage. In fact, the later Futterman amplifiers that used sweep tubes as the output tubes used this very topology. (He ran the pentode first stage in near current starvation mode to further increase its gain, which is a testament to just how little transconductance the output tubes held.) In his amplifiers the output signal was voltage shifted higher and the fed to both the top pentode's screen and the to the top of the split-load phase splitter's plate resistor.

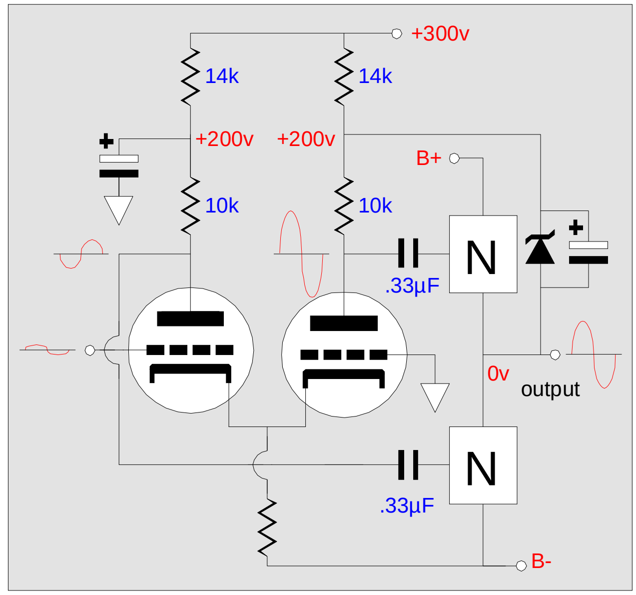
Using this topology with transistors or MOSFETs in the output stage does not require so much gain; a 5687 would work just fine. The final open-loop gain is given by the gain of the input stage against the transconductance of the output devices against the load impedance. Once again, the Class-A amplifier realizes twice the gain and half the output impedance that the Class-B amplifier yields.

The circuit shown below dispenses with the zener-capacitor combination by connecting the output to the bottom of the split-load phase splitter' cathode resistor. "Surely the top output device is working as an unity gain follower in this circuit?" is what many readers are thinking. It may look that way, but the top device still provides gain and high output impedance. Here is why. A positive pulse to the output decrease the voltage across the cathode resistor, which implies a decrease in the voltage drop across the plate resistor, which results in the positive pulse expressing itself at the input of the top output device. The top output device cannot follow what it does not see and it cannot see the positive pulse if the output and the input track each other.



The bottom output device cannot see the positive pulse because the phase splitter's cathode is locked by the unwavering grid. This topology is the one used in the first Futterman amplifiers. The output tubes used were 12B4s and the amplifier used a current starved 6AU6 as its input tube.

In the following circuit, the long tail phase splitter provides the phase splitting and the gain needed to drive the output devices. It also offers the full potential gain of the output devices working into the load and a high output impedance. It can be configured to accept feedback at the second triode's grid.



Like the other long tail phase splitter based topology, this topology is in itself sufficient for building a complete amplifier, if solid-state output devices are used. In fact, if the load is high enough, for example headphones, this topology is sufficient with tube as output devices.

Conclusion

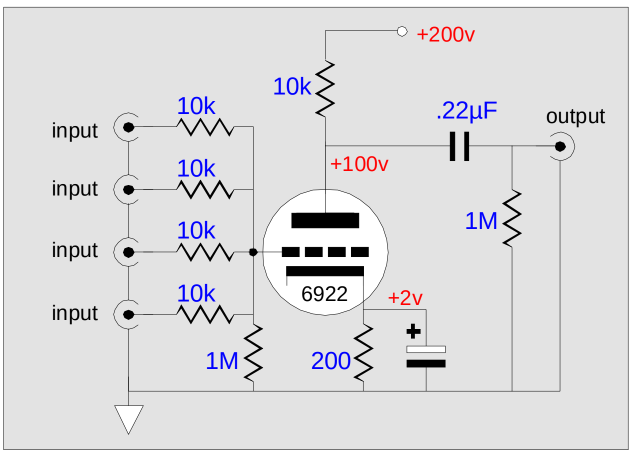
We have covered quite a bit of ground on the topic of hybrid amplifiers. We have seen how symmetrical output stages work and how unsymmetrical one works. My regret is that there is far too much still left uncovered. A truly fat book is needed to cover hybrid amplifiers. A second regret I have is that I did not provide a name for each of the six common output topologies, as names would prove handy. But I cannot think of a naming system that would cleanly and definitively label each topology. And the usual audio practice of fluff names, such as "mega-ultra-supra-linear" sickens me.

Next time, we will look into single-ended choke loaded source and emitter followers with triode front-ends. We must also look into the noise relationships within all the six output topologies. Until then, please send e-mail, if you have any questions or ideas to share.

//JRB

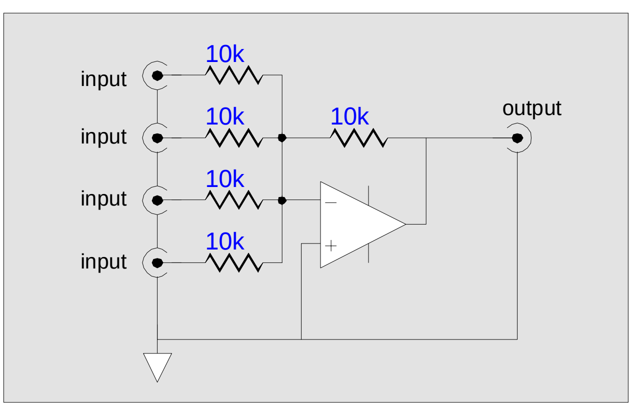
TUBE MIXERS

The mixer is an essential tool in professional audio endeavors. Bands, concert halls, recording studios, and radio stations all use mixers to blend audio signals from different sources into one signal. Ideally, the mixer only mixes at its output and not at all at its input. In other words, the input signals should not back-feed into each other. While this is small a concern when low output impedance solid-state devices are the sources, it does become a large concern when the input sources are high output impedance tube circuits. Furthermore, a mixer should not diminish or augment the signal; its job is only to mix input signals.



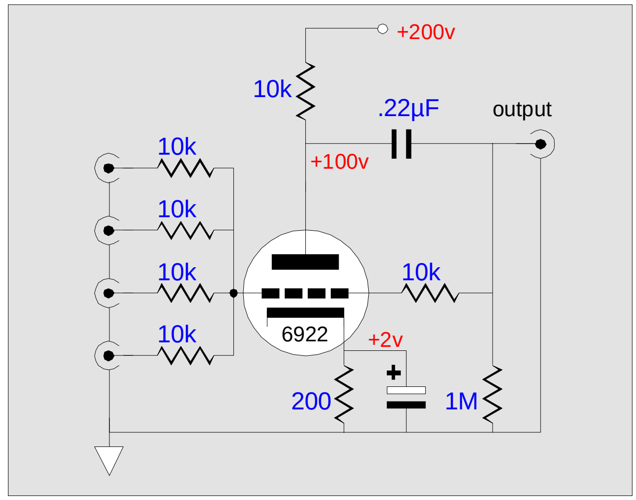
Simple tube mixer

With the advent of the solid-state Op-Amplifier, mixer design became trivial. One Op-Amp and a handful of resistor is all that is needed. The circuit below illustrates the simplicity of the modern mixer. Making an effective tube mixer requires a little more work.



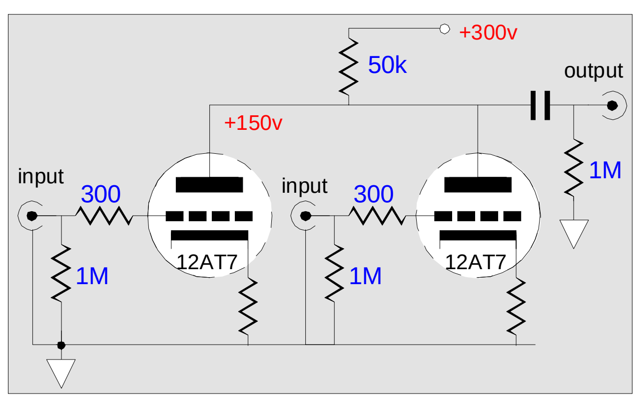
Simple IC Op-Amp mixer

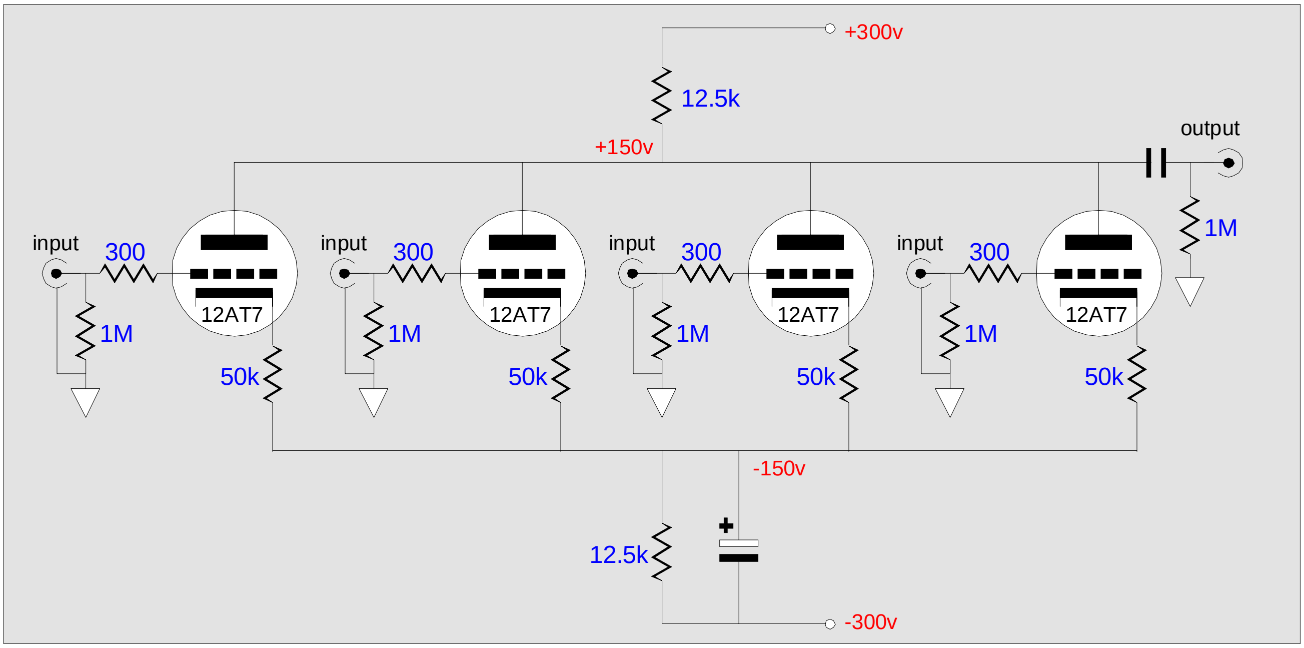
The simplest tube mixer is made up of several series input resistors feeding one common grid. The resistors further the isolation between inputs, i.e. serve to limit the back-feeding of input signals. The input signals are summed at the grid and amplifier at the plate. Unfortunately, this circuit is too simple. It fails to truly isolate the inputs; it provides unwanted gain; and it adds excessive distortion.



Feedback simple tube mixer

Adding one resistor to the circuit makes the difference. This resistor completes a feedback path that will provide much greater isolation, unity gain, and both a low distortion figure and output impedance. This circuit is the function equivalent to the previously shown Op-Amp circuit. Adding a cathode follower to the circuit will substantially lower the circuit's output impedance, as the cathode follower output is included in the feedback loop and its already low output impedance will be decreased by the feedback ratio. For many readers, we need not go any further, as they have all that they want in a tube mixer. For other readers, the feedback aspect annoys. "Couldn't a feedback-less design that functions as well be created?" they wonder. It can.



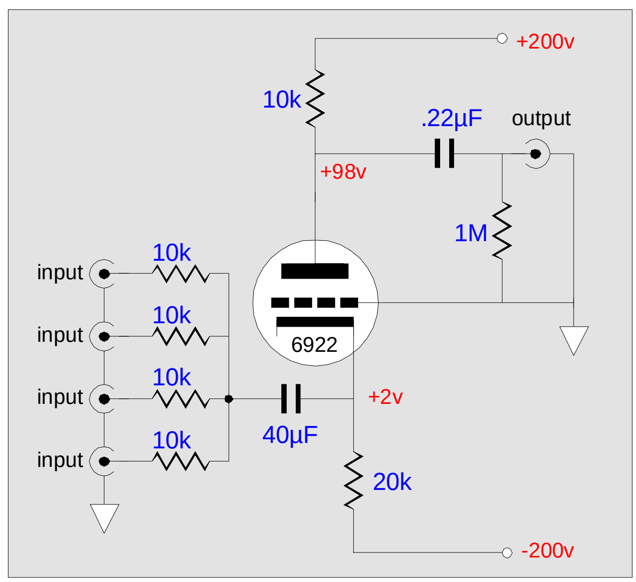


Shown above is first a common alternative to the simplest tube mixer circuit and then its improvement. Each input source finds its own triode and all of the plates are tied together. This variation provides the needed isolation, but fails to provide an unity gain output. The obvious fix, reducing the plate resistor value until the gain drops to unity, adds too much distortion and too much power supply noise at the output. Fixing these problem compels a negative power supply. A negative rail allows for a much larger valued cathode resistor. With this new cathode resistor value, the gain drops to unity, the distortion disappears, and the power supply noise drops out of equation (with a small added twist that is).

If plate and cathode resistor equal each other, then the anti-phase noise on the negative power supply rail is summed with the positive rail's noise at the plate and they cancel. But if these resistor match in value, the necessary voltage relationships within the circuit cannot exist. Adding one bypassed resistor completes the trick. This resistor's value is the same as all the cathode resistors placed in parallel. Thus, if eight inputs are needed, eight triodes and eight cathode resistors (for example, 80k) are also needed along with one 10k resistor.

If you are thinking that what we actually have eight split-load phase splitters working into one common plate resistor, you are right. The functioning is the same and final use differs. Finding what is common in what is apparently different is the key to understanding tube circuits (and life).

One disadvantage to this circuit is the need for so many triodes. How do we retain the desired functioning of the mixer and use fewer tubes and no feedback? The following circuit uses only one triode and no feedback.



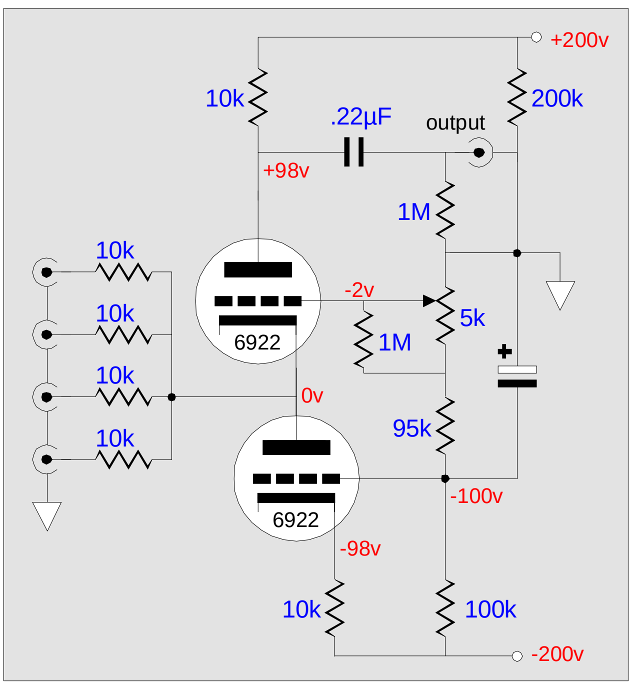
Grounded grid mixer

The input is taken at the top triode's cathode. This input point is naturally low in impedance and offers a non-inverting output signal. The exact value of the impedance at the cathode is equal to the cathode resistor value in parallel with sum of the rp and the plate resistor divided by the mu plus 1:

Zin = Rk || [(rp + Ra) / (mu +1)].

This low impedance works to isolate the inputs by forming a voltage divider with the 10k input resistors. Because the cathode rest a few volts above ground, the 40µF coupling capacitor is needed to protect the input sources from the DC offset. An alternative topology is one with a coupling capacitor per input resistor. While these coupling capacitor would be smaller in value than the single capacitor, it is a nuisance to have any coupling capacitors. Eliminating these coupling capacitors requires giving the grid a counter bias voltage sufficient to bring the cathode to ground level. And the power supply noise can lessened by the same partial cathode resistor bypass trick as used in the last circuit.

Further hotrodding of the this circuit entails replacing the cathode resistor with a current source. The current source subtlety improves the mixer's performance. The actual effective impedance of the current source is equal to the rp added to the cathode resistor against the mu plus 1. In this example, 343k is the effective value.

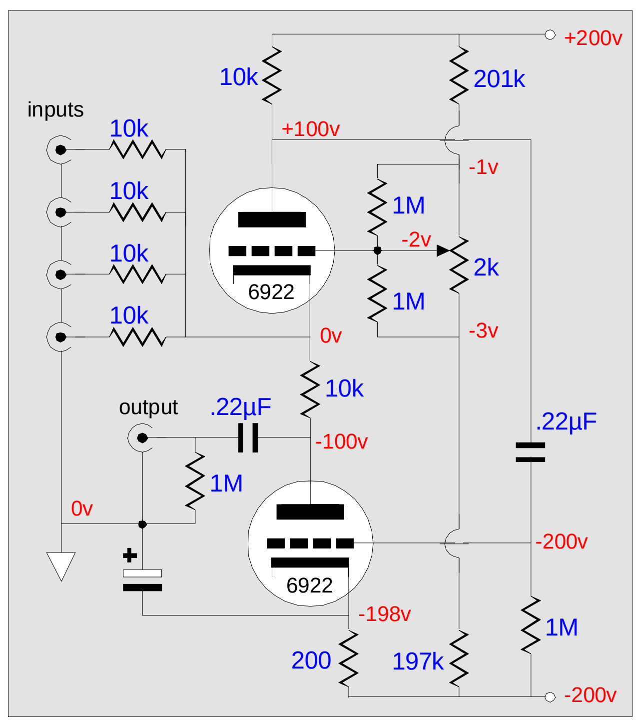


The current source loaded mixer design

Note the placement of the electrolytic capacitor. It purposely does not connect to the negative power supply rail, as we need to interject some anti-phase power supply noise to cancel noise at the output. The potentiometer allows for easy DC offset adjustments. And the heater should be referenced to –50 volts to split the difference between the cathodes.

Some readers might be having a hard time understanding how this circuit works. The key is to think current and not voltage. A +1 volt pulse at the input of one of the 10k resistors leads to a .1 mA pulse at the top triode's cathode. Now the question is where will the current pulse go? The current source is maintaining a constant current draw so it cannot easily up its conduction. This leaves the top triode to give up .1 mA less conduction. And as the plate resistor is in series with the triode, its voltage drop must decrease by .1 mA against its 10k value. In other words, the top triode's plate sees a +1 volt pulse. In contrast, a negative going 1 volt pulse at the input will force the top triode to increase its conduction by .1 mA and thus pull its plate down by one volt.

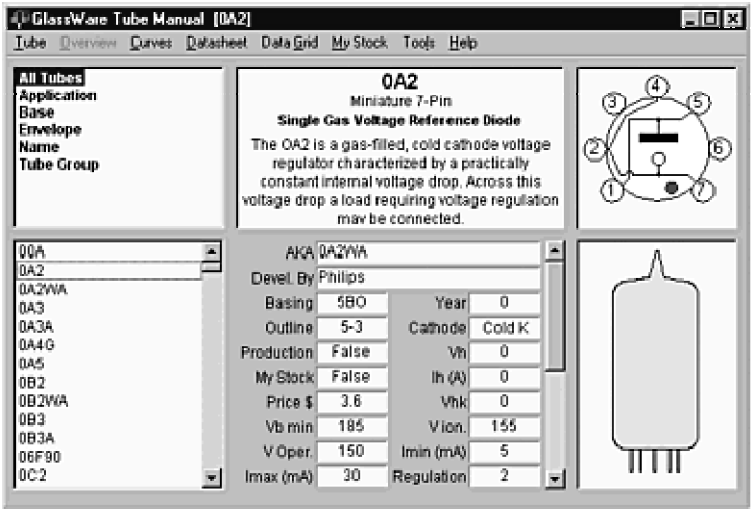
A further modification of this circuit is to apply a White-cathode-follower like topology to the circuit. Shown below is the result. The output is taken at the bottom of the center 10k resistor and is consequently phase inverted. The .22µF capacitor supplies a feedback path from the plate of the top triode. The feedback works to lower the impedance at the top triode's cathode by utilizes the transconductance of both the tubes. The potential danger to this circuit is the large voltage potential between the two cathodes. This requires using two separate tube envelopes and two floating heater power supplies.



White cathode follower inspired mixer design

NEW

GLASSWARE TUBE MANUAL



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A true 32-bit Windows program, GlassWare Tube Manual is both user friendly and powerful. It's all here: plate curves, mu, rp, Gm, Vh, Ih, base and outline schematics, and essential characteristics for many of the tubes. Powerful search and filtering tools give control over this tube manual's large library of tubes (11,000). Look up your favorite tubes (6SN7, KT88, 2A3, and 6922) and discover other great tubes you didn't know existed. With the aid of easy-to-use editing tools, tubes can be added or subtracted to the database. Keep track of your own tube collection with your personal tube database. Like all GlassWare programs, GlassWare Tube Manual allows you to print the results. Hard copies of all the tubes in in this tube manual are a button click away. And tube substitutions are given for over 2000 tube types.

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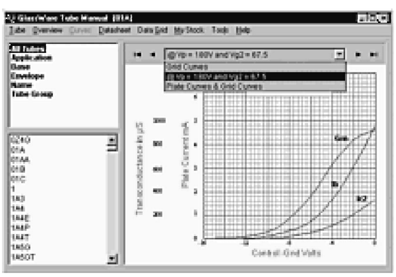
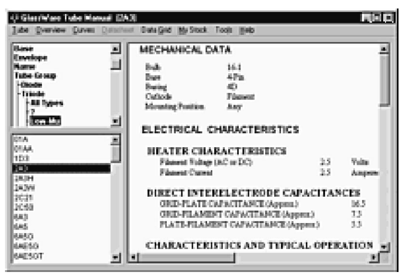
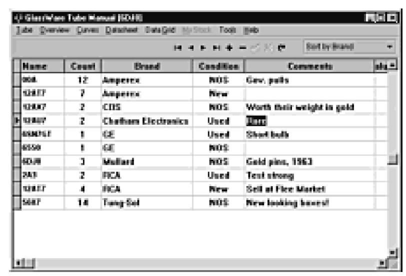


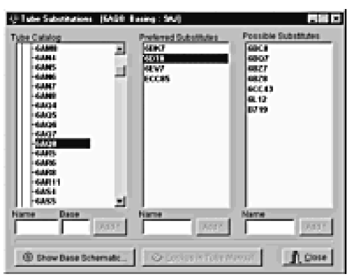
Plate Curves



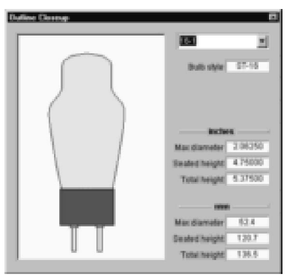
Datasheets



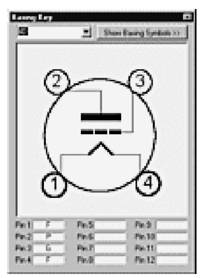
User's own stock DB



Tube Substitutions

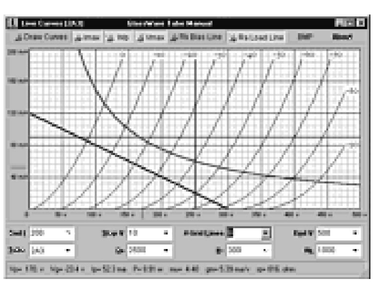


Tube Outlines

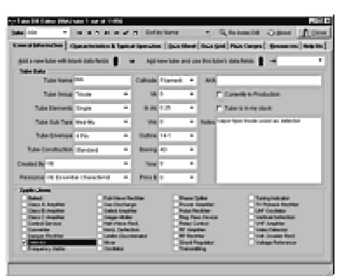


Tube Basing

Complex DB Filtering



Live Curves for over 40 tubes



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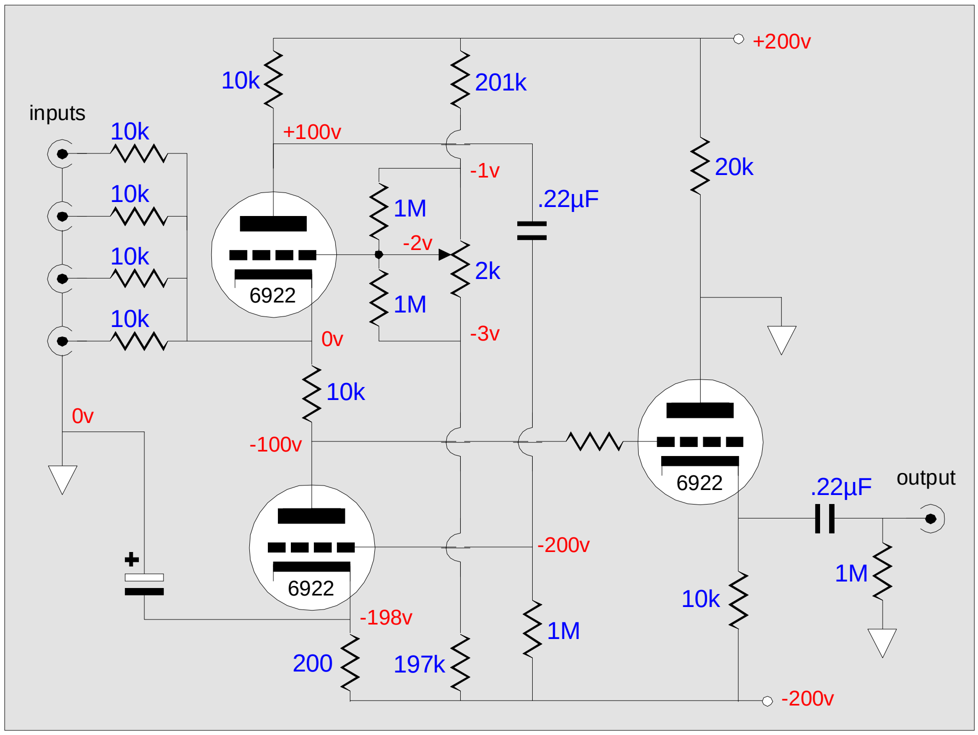
A further disadvantage to this circuit is the fact that we have swapped potentially large current swings at the output for a lower input impedance. In other words, this variation should not be used to drive following low input impedance sources. (Imagine driving a dead short. What would be the output current swings into this load?)

The easy work around is to add a cathode follower to the output. This would free up the mixer from having to drive low impedance loads. The 20k resistor that spans ground to B+ is there to balance the entire circuit's current draw in relation to both power supply rails.

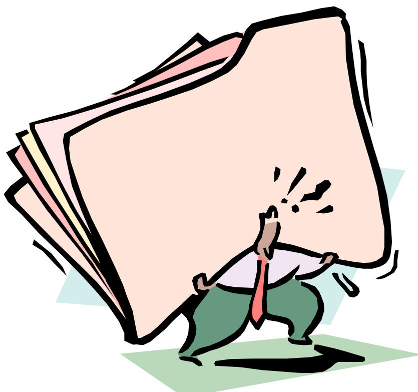
//JRB

White cathode follower inspired mixer design with a cathode follower output stage



Coming Next Issue

I am going to stop predicting what will show up in the next issue, since most of the articles have been a result of letters from readers, which usually arrive after the prediction is made.



Link of the Month

Elliott Sound Products
www.sound.au.com

Rod Elliot is a gutsy Australian (are there any other kind of Australians?) who has put a good deal of work into providing an excellent resource for us audiophiles. Although his web site is primarily devoted to solid-state circuits, there is plenty of tube related information there as well.

Beginners will find several first-step articles that are well worth reading. And experienced electronic practitioners will find his explication of solid-state amplifier design illuminating and a little controversial, which is part of the reason of why I am so heartedly recommending this web site. Solid-state design is not completely mapped out; there is still plenty of innovation and discovery to be had.

In addition, he sells circuit boards for the projects he describes at a reasonable price and his design services.

E-Mail

E-Mail from where?

The rule has been to omit last names and e-mail addresses unless the writer had clearly expressed for their inclusion. This rule will continue. However, a few readers have asked that all e-mails include the country of the sender. I like this idea and hope to see these inclusions. So please where are you from?

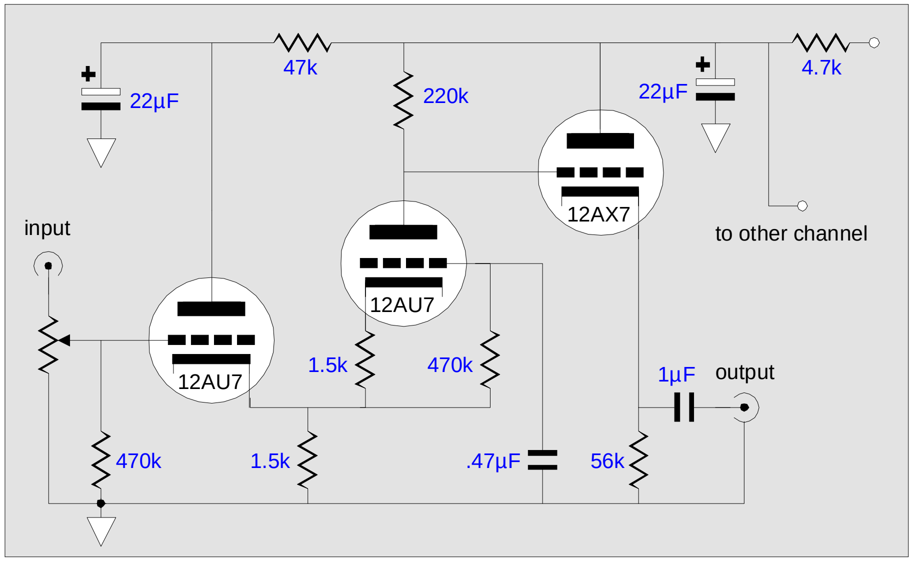
Subject: Another plea for circuit help

I do really hate asking JRB for help, as I realize that the Tube CAD Journal is devoted to what is possible, not what is broken. But I own such a poor sounding line stage amplifier that I am desperate. I now easily understand how the world switched from the vacuum-state to solid-state. It is an Antique Sound Labs AQ-2004 line stage. It looks cute, but sounds absolutely dead. My friends tell me to spend a few hundred dollars on part upgrades, which I just cannot afford right now. Two years ago I would thought that this was the only option. Today, after having spent the last year reading this journal, I know better: something is wrong with the topology and execution, not just the part quality.

My guess is that the 12AU7 input tubes and the 12AX7 cathode follower are mis-biased and that the first stage should be drastically modified or removed. If you have the time and the wish to help me, I will be greatly thankful; if not, I understand, as you must get hundreds of requests per year. Thanks anyway for such a great FREE resource (much better than the late *Glass Audio*) for us tube lovers.

Paul
Canada

Reader Paul's stock AQ-2004 line stage amplifier



First of all, thanks for providing the schematic. I get requests like yours but without schematics. Am I really expected to hunt down one? Second, I commend you for moving up out of the mere part-exchanger mentality into the higher realm of tube circuit understanding; very few audiophiles do. An acquaintance's single-ended tube amplifier disappointed him. So he bought the most expensive tubes he could find. It still disappoints. Its bandwidth begins to fall off at 8 kHz. And no amount of part exchanging is going to extend it. When told this, his reply was that was not what the people who sell expensive parts tell him (amazing, considering that those part sellers have not seen the circuit or even know how to use a scope.)

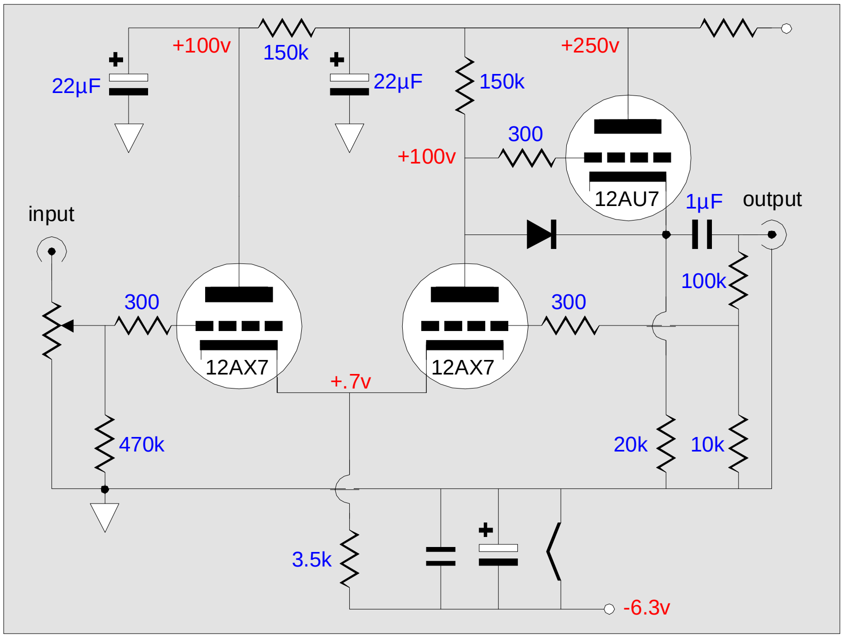
As for the line stage, you are right: it looks very cute. So cute that it would tempting to buy one and then gut all the original circuitry, as the circuit is about as unfortunate a design as I could imagine. A 12AX7 output stage??? Usually, we need only to look at the parts quality to see where an amplifier went wrong. But in this case, the part quality is relatively high. What went wrong was a poor circuit design. Just about any other circuit would be preferable and I can think of about five possibilities that would retain the same amount of tubes and many of the parts of the original. But first let's look into what is already there.

After a volume control, the signal passes to a cathode follower that then cascades into a grounded grid amplifier, which in turn, cascades into a cathode follower output stage. Another way of looking at the circuit is that it is made up of a common cathode amplifier cascading into a cathode follower.

Either way the 1500 ohm cathode resistor shared by both halves of the 12AU7 is suboptimal. It implies a miniscule idle current for both triodes and a very nonlinear operation. No doubt its value was chosen to increase the voltage drop across its leads rather than pay the price of using a negative power supply or not to tax a wimpy power transformer. Additionally, the 12AX7 output tube makes little sense, as the tube's miniscule current draw cannot overcome long lengths of capacitive interconnect or drive amplifier with low impedance inputs. Oddly enough, I have seen other similar designs. Strange.

The easiest rework of the existing circuit would be to connect the positive portion of the heater power supply to ground and thus create a negative power supply of –6.3 volts. This negative power supply would then feed the common cathode resistor. The value for this resistor is still too low for an adequate current draw for the 12AU7! A 12AU7 should have an idle current of at least 5 mA per triode, which would require a common cathode resistor value of 1k. This brings up a concern I have with the power supply: just how strong is it? Can it support any increase in current draw? I suspect it cannot and thus the wimpy idle current and tube selection. The potted power transformer looks good, but it also hides the actual size of transformer inside.

If the power supply is at its current limit, then the best move would be to use the 12AX7 as the input tube and the 12AU7 as the output tube. The common cathode topology is retained. And as the 12AX7 will provide far too much gain, a feedback loop is used to lower the final gain of the line stage.

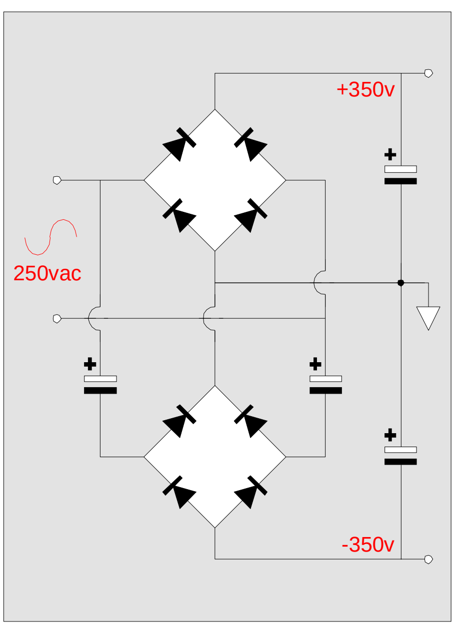


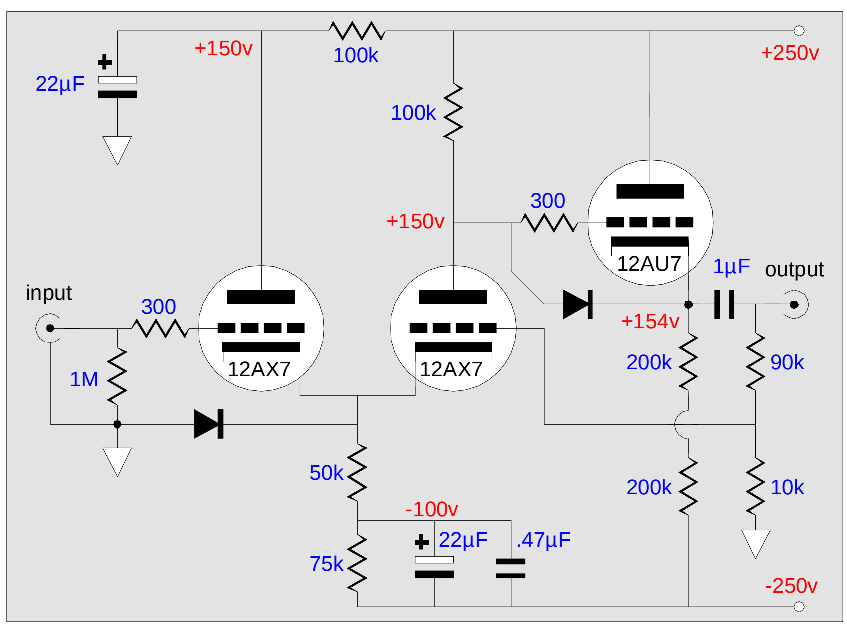
Unfortunately, the power transformer in this line stage is not center-tapped, which would have offer an easy means to creating a negative rail. The above circuit, however, will do the job. It is a effectively a voltage doubler that creates a negative power supply voltage. The extra negative voltage provided will allow a more optimal choice of operating voltages within the amplifier. The problem we faced in the earlier design was the danger of too great a voltage difference between the output tube's cathode and its heater. This forced us to accept a relatively low plate voltage for the 12AX7, as this voltage DC coupled to the 12AU7's grid.

If the negative power supply prove too noisy, the common cathode resistor can be replaced with a 1N5305 FET current source. Grid stopper resistors have been liberally added. And a safety diode protects the cathode follower at turn-on. So what we have is remake that will sound much better and still work within the present limits of the line stage.

On the other hand, if the power supply is much bolder than I have imagined, the number of potential circuit climbs. In fact, if the power supply is only marginally stronger, then using a high voltage negative power supply rail may be possible.

By freeing up the heater power supply, however, we can safely increase the 12AX7's plate voltage, as we can reference the heater power supply at +75 volts above ground; thus, splitting the voltage difference between the 12AX7 and 12AU7's cathodes. Shown below is the version with a high voltage bipolar power supply. The often recommended (in this journal at least) power supply noise reduction trick is implemented at the negative side of the power supply. The 75k resistor is bypassed to increase the amount of negative power supply noise into the 50k common cathode resistor.

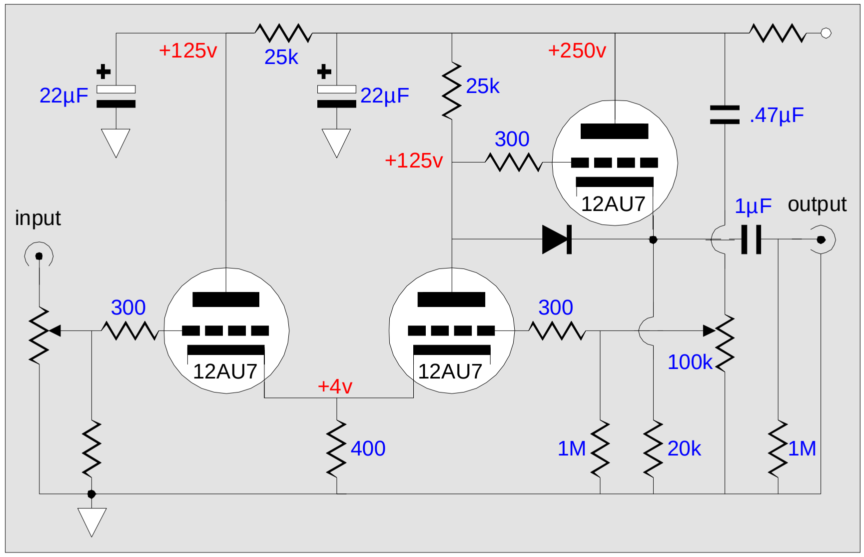


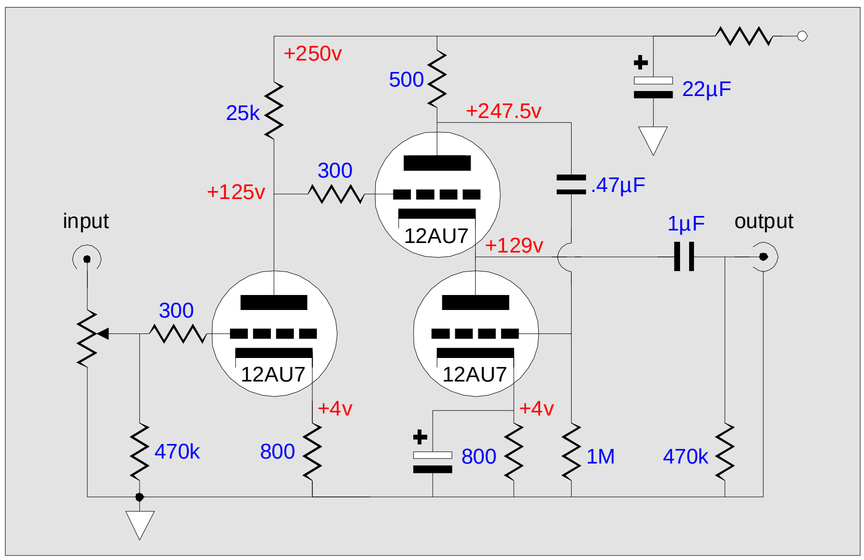


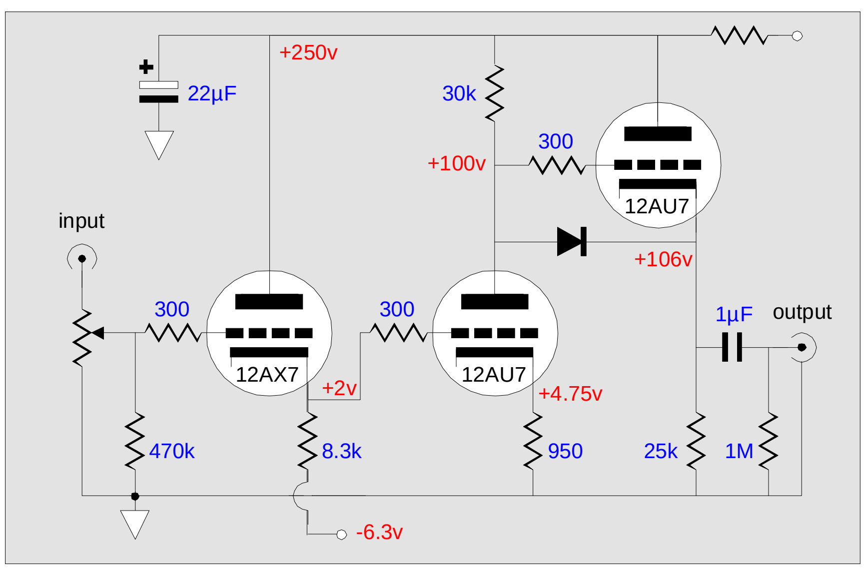
An alternative circuit is shown at the right. It uses a mono-polar power supply and only 12AU7s. No feedback is used and total idle current equals 15 mA per channel. The power supply noise that makes to the output is nulled out by adjusting the amount of power supply noise at the second triode's grid. This *signal* is phase inverted at the plate where it then cancels. The heater power supply should be reference to +75 volts. To avoid having the front-end adding too much distortion to this amplifier, the common cathode resistor can be replaced with a current source.

The next circuit to the right also uses only 12AU7s and uses a White cathode follower at its output. The circuit below it uses a 12AX7 as an input tube configured as a cathode follower. While probably unnecessary, the cathode follower will extend the bandwidth of the line-stage amplifier.

Both of these circuits invert the output phase. This will upset some audiophiles unnecessarily, as all that is required to set thing straight is to invert the wires leading to the speakers. Yet, some audiophiles balk at the suggestion. Let's imagine a comparable situation. A man walks up to a saleswoman at a bookstore and displays a book held upside down in his hand. He says that this book is the last of its type in the store and he would gladly buy if the printers hadn't printed it upside down. The saleswomen asks why he doesn't turn the book around. He snootily replies that he does buy misprinted books period. She informs that the manager has one copy of the same book in the backroom and that she is willing to swap the books if he wishes. She returns with the righted book and the customer is happy.







Paul, I bet you are wondering which circuit is best. Unfortunately, you will have to do the work to find out. It is doubly unfortunate that the manufacturer hadn't done in the first place, as what works best is to build all the circuits at once, which of course requires many chassis and parts. Then give all the line stages to one listener for a few days. (By the way, only one set of tubes would be given so that the tube variable could be held constant.) Next, the many line stages would go to another home for three days. After about five such trips, a tally of preferred units is taken. The winner (or winners) is then duplicated. So now there are two identical line stages. The next step is to review the criticisms of the winning unit and modifications are made to only one copy in an attempt to improve it in those areas where it found complaints. A second round of traveling to different homes begins, but this time for only one day. If the modification did the trick, the unmodified unit is then given the same modification. (If it failed, the modification is removed and another put in its place.) And a second round of modification is made to one unit for evaluation. And so on… It is much like mountain climbing: you do not move up until you have secured your present position. Even this just described elaborate method is truncated, as it should be applied to all the proposed circuits first and then a final shootout can be made.

The alternative method is the one most commonly used: only one unit undergoes many modifications and some progress is other times it is lost and other times a giant step sideways is taken. The longer the modifications took to implement, the poorer the comparison's reliability. Additionally, or rather subtractively, since all of the modifications were evaluated on just one system, the results are seldom universal. In other words, the unit was optimized to compensate for the fallings of just one system. This is good news if the system belongs to you, but bad news for others with different systems.

One quick test I recommend is that you wire a high wattage 20k resistor across the first power supply filter capacitor. This will test if the power transformer to see if it can sustain any added current draw. If the B+ voltage falls drastically or excess hum from the speakers or buzz from the power transformer is heard or the power transformer becomes excessively hot, it cannot handle the increased load. Adding a separate transformer inside the chassis for just the heaters will help unload the potted transformer.

Details not covered: the power supply diodes should be replaced with high-speed Hexfreds and the power supply dropping resistors values must be changed if a higher current draw is used. The heater power supply must be somehow reference to the main power supply and should not be left to float completely.

Bytheway, thanks for the kind words, but careful with the comparisons with demised, or rather transmuted, *Glass Audio*, as I have already been accused of contributing to its demise by one reader. Paul, you have got some work ahead of you. Good luck and keep us updated with your progress.

Subject: Headphone amp

First of all, thank you for publishing such very useful information for free. I really enjoy studying your web magazine, although I don't understand everything. This leads me to my question:

I consider building a headphone amp for my Sennheiser HD580. Your circuit in http://www.tubecad.com/july99/ is really interesting, but I don't know how to calculate the gain of the amp. For my HD580 I need a max, output voltage of 7.7V (300 Ohms and 200 mW max.). Can I calculate the input-stage gain with the same formula as used for the grounded cathode amplifier (with Rp=20K and Rk = 930 Ohms)? Can you give some me further explanation regarding this input stage?

I've also seen the circuit of the month in http://www.glass-ware.com/tubecircuits/Tube_Headphone_Amplifier.html. But I don't like the low input impedance. So, what do you think about removing the 150k resistor and instead grounding the grid with a 1 Meg? Thank you in advance for your help.

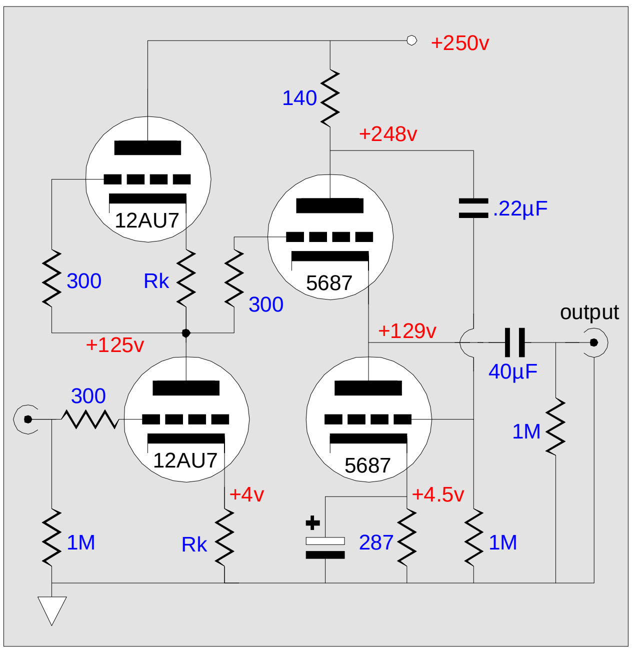
Daniel
Germany

I also own the HD580 and I have measured (on a scope) the music signal delivered to the headphones. Even at excruciating sound levels the signal remained under 2 volts. (I must reveal that I listen to music at a much lower volume than any other audiophile I have ever met.) In other words, I am not convinced that we need 200 mW. Of course, spare power is reassuring. Either of these two circuits will provide a healthy output into HD580s. Both circuits will work with these headphones. The gain of the first circuit is set by the roughly the same formula as the grounded cathode amplifier:

Gain = muRa / (Ra + 2rp)

Consequently, a 6AQ8 will yield a higher gain; the 12AU7, a lower gain. Changing the input tube will, however, also require changing the noise cancellation voltage divider's resistor ratio. A potentiometer might be the best idea.

The second circuit uses the ratio of the input resistor divided into the feedback resistor to set the gain, which must be less than the open-loop gain of the amplifier. Increasing the input resistor's value runs the risk of limiting the high frequency response of the amplifier because of the Miller effect capacitance. Nonetheless, I am sure that we do not need bandwidth to 1 MHz in a headphone amplifier.



Headphone amplifier for 300 ohm loads

The circuit I am building today is shown above. A variation on this circuit was briefly covered in the last issue and in a previous letter in this issue. It uses an optimally designed White cathode follower as an output stage, wherein Ra equals the reciprocal of the triode's Gm. The input stage is a simple grounded cathode amplifier with an active load. By using the same triodes and the same valued cathode resistors, the gain is easy to compute:

Gain = muRa / (Ra + rp + (mu + 1)Rk)

In this case,

Ra = (mu + 1)Rk + rp

Substituting yields:

$$\text{Gain} = \frac{mu[(mu + 1)Rk + rp]}{(mu + 1)Rk + rp + (mu + 1)Rk + rp}$$

Which reduces to **Gain = mu / 2**.

Thus, the gain can be set by using different input tubes, such as the 12AU7, 12AT7, 12AV7, 12AX7, 12BH7, 12FQ8, 5751, 5963, 5965, 6072, 6211, and the E80CC, without having to change the values of the cathode resistors. For octal fans, the only two real choices are the 6SN7 and the 6SL7.

The beauty of this input stage is that it must also halve the power supply noise, as it forms a ½ voltage divider. And halving the noise is what the output stage needs to see in order to ignore the noise at its output. The output tube can be any low mu, low rp triode. I like the 5687 because its linearity and its huge cathode, which allows for huge current draws. The downside to this triode it its 0.9 amp heater current draw. Other triodes that can be used are the 12AU7, 6XB7, 6BL7, 6922, 12B4, 12BH7, 12FQ8, E288CC, and the 6AC7 triode connected or 6V6 or 6BQ5 or 12BY7.

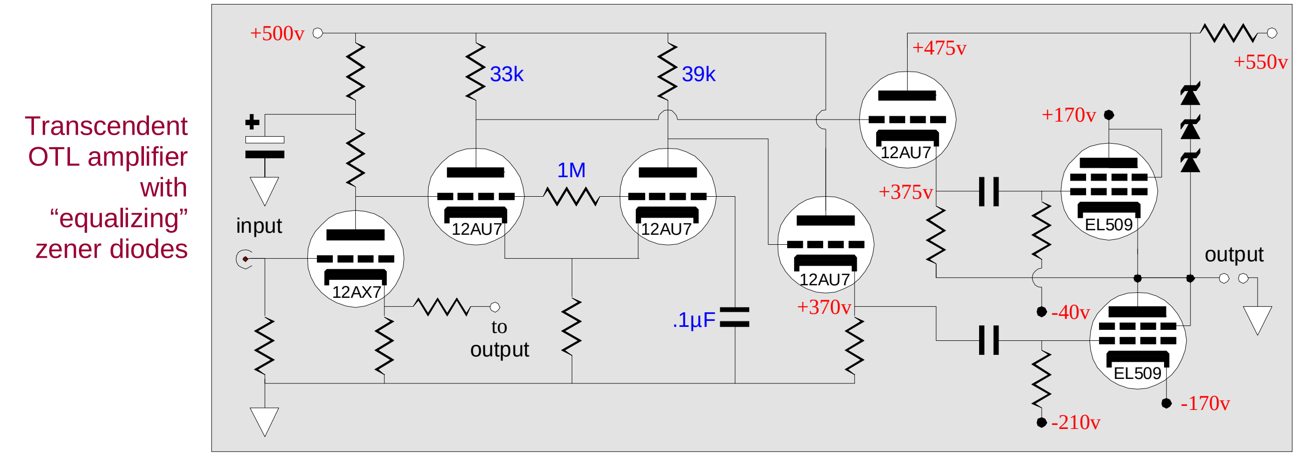
I plan to use this circuit as line stage amplifier / headphone amplifier. When its function is driving the power amplifiers, the output coupling capacitor will be only a 1µF InfiniCap. When its function is driving the headphones, the output coupling capacitor will consist of the InfiniCap in parallel with a 40µF Solen polypropylene capacitor. The power supply will be kept in a remote box and will use a choke based filter rather than a voltage regulator.

Subject: Concerning "5687 black plate tube"

Recently I came across a preamp schematic called "Pat's ultimate preamp." It talks about 5687 black plate tube. It also says: "I fine-tuned it in Tube CAD" Do you have any further details about this? I would like to build a tube preamp for my dry sounding transistor guitar amplifier

Kai,
Norway

The 5687 is mentioned in the answer to the last e-mail. I own about 40 5687s, but I do not know how many, if any, are "black" plate, so I cannot comment on their sound. Tube CAD is a tube circuit analysis program that I wrote. It contains 52 circuit topologies and costs $39. I use it almost every day in my tube design work and although it is not perfect, I recommend it anyone who builds tube projects. The best place to read about it is the GlassWare web site at http:/www.glass-ware.com .



Subject: Transcendent OTL

I want to refer to schematic of the Transcendent OTL in you November 1999 issue http://www.tubecad.com/november99. It appears to me that the totem pole is operating at different gain despite of the claim.

The upper tube is a cathode follower, so it is bootstrapped to compensate for the 100% feedback so it's of unity gain. But the lower tube is still a common cathode stage with some gain of EL509. The driver stage has no feedback to reduce the gain of lower tube to the same level as the upper tube. It appears that a lot more negative feedback is required to correct this, do you agree?

Another thing is that the drive requirement for full output is as follow, assuming 90% efficiency of the cathode follower.

Upper tube:

Drive voltage = (grid voltage swing / 0.9) + output voltage.

Bottom tube:

Drive voltage = grid voltage swing

And thus the total drive required must be the same as upper tube, am I correct?

p. k.

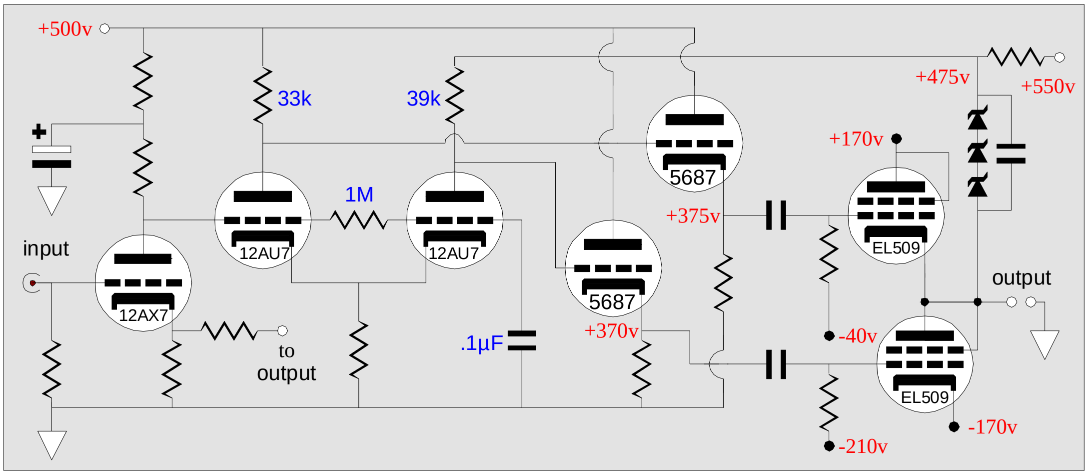
?

Yes, your insight is right on. The patented equalization drive signal mechanism implemented in the Transcendent OTL, the basis for starting the company in fact, does not equalize the drive signal for the bottom and top tubes. Sad to say, I cannot recommend this trick for anything other than ensuring that the top cathode follower has some plate voltage available to it, which adding a hundred volts to the driver stage power supply would also ensure.

In other words, the zeners diodes helps this amplifier out of the corner the designer had painted it into to: at idle, the bottom cathode follower sees 130 volts from cathode-to-plate and the top cathode follower only sees 100 volts. (Using a 5687 instead of the 12AU7 would be a better choice for the cathode followers, as the 5687 has a greater low voltage operating range.) But it does not equalize the drive signals for the output tubes. To verify this disconnect the feedback resistor and observe the output waveform (my choice is the triangle-wave, as its straight lines reveal bending much more readily than the sine-wave). An added sad fact is that long tail phase splitter’s plate resistors were chosen to ensure an equal output voltage swings from the plate resistors, which is not what the output stage needs to deliver a clean output voltage swing.

So how do we fix this amplifier? The easiest path would be to couple the long tail phase splitter’s second plate resistor to the top of the zener string, rather than to the B+ connection. On the next page you will find the schematic. This modification will equalize the drive voltage for the bottom output tubes (and is covered in this issue’s article on hybrid amplifiers). Now the tubes are both working as cathode followers. A positive pulse applied to the output will be bucked equally by both tubes, as the pulse will be relayed to the bottom tube’s grid and the top tube’s grid is fixed. Once again, to verify this proposition disconnect the feedback resistor and observe the output waveform. Your formulae will not apply here, but would (minus the / .9) if the zener string is attached to the long tail phase splitter’s first triode’s plate resistor instead. Maybe in the next issue, we will do a complete rework of this and other OTL amplifiers, cleaning up power supply noise problems and equalizing drive voltages.

Improved OTL amplifier with true drive equalization



Subject: Simple amplifier questions

I am interested in building the amp in the September 1999 issue Volume 1 Number 7. I have a transformer a secondary rated at 320v-0-320v @ 300 mA which after rectification with a 5R4GA rectifier tube I wind up with approximately 460v DC. I have 3 questions:

1) how to bring the plate voltage down to 360 vdc as described in the article without slowing down the capacitor recharge time?

2) isn't this plate voltage too high? The manual for the 6BQ5 recommends 250v operated in SE triode mode?

3) can you send me more exact information on how to wire the 6BQ5 in triode mode?

Bill

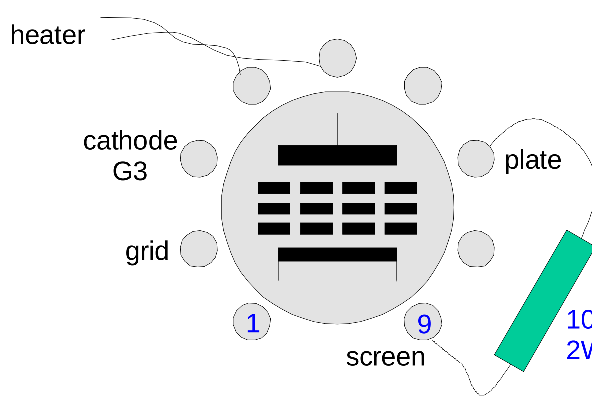
The 360 volt power supply was arbitrarily chosen to match what a 115-to-240 volts step-up transformer yield when rectified with an input wall voltage of 121vac. My guess is that your power supply will naturally lose 20 to 40 volts when loaded by a stereo amplifier, which will move the B+ closer to the 360 volts.

1) The power supply in an SE amplifier sees a fairly constant current draw, as the output transformer's inductance buffers the power supply from the power amplifiers current variations as it traces the output signal. Consequently, adding a dropping resistor and a filtering capacitor will not harm the amplifier. In fact, it will decrease the power supply noise at the output.

2) The 6BQ5/7189A/EL84 is a tough little tube. I have seen them work handsomely in Dynaco ST-35 and SCA-35 amplifiers (with 380 volts power supplies and 35 mA cathode currents) for decades. The Philips ECG tube manual gives a maximum plate voltage of 300 volts for the 6BQ5 and 440 volts for the 7189A, which in actual practice may prove to be a distinction without a difference. My guess is that poorly made American tubes were labeled "6BQ5" and well made European tubes were labeled "7189A."

The problem with tube maximum ratings is that they are not absolute in the same way solid-state maximum ratings are. If a transistor sees twice the maximum collector-to-emitter voltage, it burns out. If a tube sees twice its maximum plate voltage rating, no damage may result if there is no arcing and the over-voltage is short-lived. (In a transformer coupled amplifier the plate voltage will nearly double with every half cycle.) With solid-state devices, the maximum ratings are like having the highway patrol bazooka any car that exceeds the speed limit. With tubes, the maximum ratings are like driving your car at a hundred miles per hour; your car will not last as long as it would at 55 MPH, but it will not instantly breakdown.

3) Shown below is the bottom view of the tube.



Subject: July 1999's email section

First of all, I would to thank you for such an informative website and I hope that you keep up the good work. Looking back in July 1999's email section on David's inquiry about non-inverting headphone amp, I am wondering if he or anybody had actually built the amp and posted a result. I would really be interested to know how it went. By looking at the circuit, it looks awesome and I'm planning to build it as soon as I get all the tubes I need. I have a couple of flat pack power transformers with double primary and secondary windings (115/230 volts to 12/6 volts, 48VA) that I'd like to use. I intend to use the secondary windings as the primary and hook it via wall wart with equivalent rating of course. I also would like to try a 6X5 tube rectifier in the power supply. I don't have enough data for the diode to see if I get about 170V to supply the amp. This is merely a design idea which needs further examinations. My intention is to power your designed circuit with tube rectification using the materials readily available. I would really appreciate it if you could give me some feedback on this. I am physics major student but I've always loved tinkering with electronics and appreciates tube sound. Thanks.
C.A.

No one yet has written about his results. If anyone has results, please let us know about them.

Finding a 48VA wall wart transformer will not be easy. So might have to use another flat-pack transformer boxed in a remote enclosure in place of the wall wart. Effectively the backwards flat-pack transformer becomes a 230 VAC center-tapped transformer, which would work well with 6X5 rectifier. This rectifier differs from most in that its heater is separate from the cathode, which means that separate heater winding is not necessary, as long as the voltage differential between cathode and heater does not exceed 450 volts. Unfortunately, I do not think you will achieve the full 170 volts, as the rectifier has a plate impedance of about 150 ohms per plate, which will result in about a 10 to 15 volt drop in the potential B+ voltage. My suggestion is to make do with whatever B+ voltage you might wring from the power supply and compensate elsewhere. This means that the plate resistor values will have to be scaled down a bit and with them the noise canceling resistor values. Please keep us posted with your results, as many reader are on the same path.

Subject: Small OTL amp

First of all: thanks for a inspiring webzine with lots of good ideas. If I only had time to try it all...

Then the questions: I'm in the planning stage of a small OTL amp for my midrange horns, so I do only need 2-3 watts in 8 ohms, and I want to optimize it for the 200Hz and up range. But I'm not sure what output stage topology to use. Fist I thought maybe an SRPP stage could be used, but the current plan is to use the cathode follower driven circlotron from the December issue, and use the common-mode choke coupled version. I plan to use 6SN7 as cathode follower. Will this require great changes in the component values? And how much drive do I need, if I use 6AS7 (how many do I need)? Since this is a midrange amp, I can use capacitor coupling at the output. I want to use as little global feedback as possible, and preferably class A, or maybe slightly into class AB above 2W. What is the output impedance of this circuit?

Subject: Small OTL amp, correction

I have to correct my last mail: I wrote "...to use the cathode follower driven circlotron...", but of course I see that it's not cathode follower driven.

Another question: If I use a 110+110:110+110 volts transformer as common mode chokes, is this good enough? Will the sound quality be worse with the transformer?

Bjørn
Norway

The last question first: the 110+110:110+110 volts transformer might not have a 1:1 winding ratio, as the ration in isolation transformers are often skewed to compensate for voltage losses in the transformer. I once bought a transformer with a 115VAC primary and a 108VAC secondary. Its winding ratio was one to one, but after being loaded, the secondary voltage lost 7 volts. Test the transformer without loading it.

Now for the big first question: How to design a 4 watt OTL amplifier? First of all, I think the world could certainly use a great 4 watt OTL amplifier. Many of friends are running highly efficient horn load speakers with 3 watt single-ended amplifiers and adding the choice of an OTL amplifier would be for the good. But before embarking on this trip, check to see if anyone has gone there before you. Julius Futterman first amplifier is a good start.

This amplifier a clever way to *inexpensively* make a high quality amplifier, as it used relatively cheap tubes and no output coupling capacitor nor output transformer (nor even a power transformer for the output stage). So why not build it today, tarted up a bit with high quality parts and power supply regulation? Simply, I do not think it will work as well as it once did. Not in its original form that is.

Here is why.

The original amplifier used eight 12B4s and put out 12 watts into a 16 ohm load. Today we use 4-8 ohm speakers. The peak (non-positive grid) output current a triode is capable of delivering into a load resistance is given by

Ipk = B+ / (rp + Rload).

Since the rp of even four parallel 12B4s is much higher than any speaker impedance, the peak output current doesn't differ much between the 8 and 16 ohm load, but the peak output voltage is halved. In other words, the amplifier can only put out 5 watts into a 8 ohm load. Yes, 5 watts is more than any single 2A3 SE amplifier puts out and it is more than enough for a high efficiency midrange. (Now if the number of output tubes is doubled, the full 12 watts is possible. Since 12B4s are so cheap, doubling the number will not add much to the cost of the amplifier. Besides, as the amplifier runs in a lean Class-AB, each 12B4 dissipate less than 1 watt of heat at idle and should last forever.)

If you wish to have only a Class-A OTL, then more or different output tubes will be needed. Here is an example of seductive thinking: commercially made OTL amplifiers use eight 6AS7s and they supposedly put out 60 watts of Class-A power; thus, one 6AS7 can put out 8 watts of Class-A power. Seductive, as only the truly false and misleading can be. First of all, these amplifiers only put out about 4 watts of Class-A power. So using the ratio method, one 6AS7 should put out half a watt of Class-A power; it still can't. The math falls apart because of the squared terms in the power calculations: double the output current or the output voltage and you quadruple the output wattage.

Inversely, halving the output current or voltage, quarters the output wattage. This is the result of one variable's increase implying the increase of the other variable:

$$P = \frac{1}{2} I^2 R$$

and

$$P = V^2 / 2R \quad \text{(RMS watts).}$$

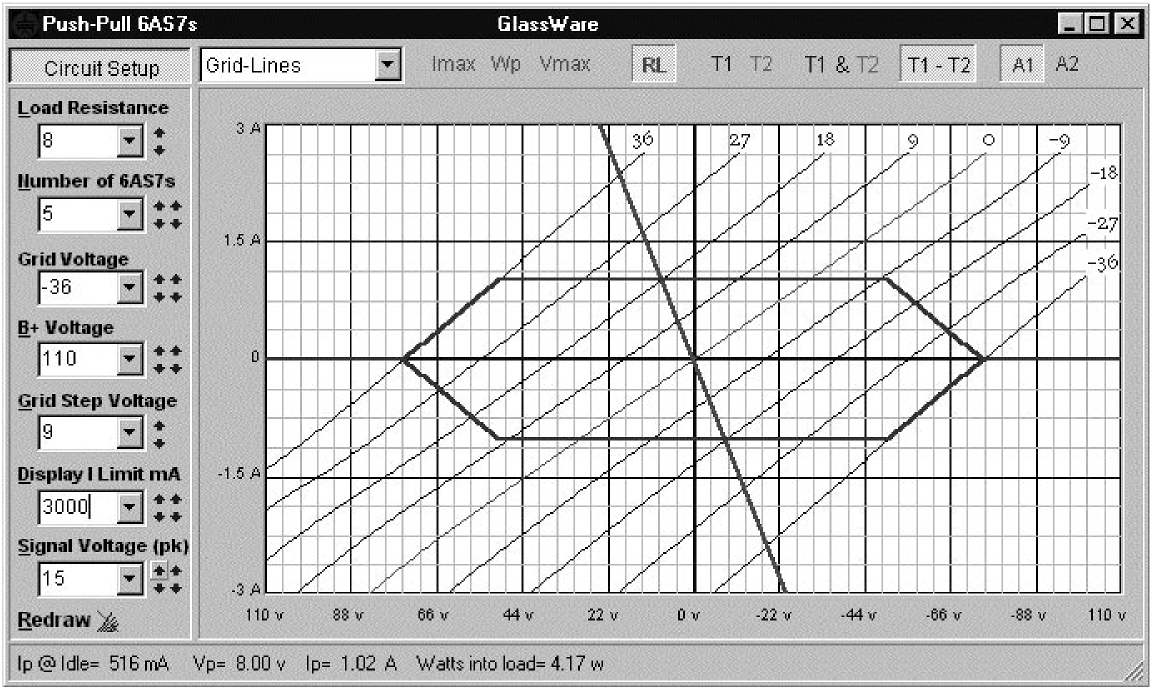
The big problem that tube OTL amplifiers face is that the tubes are severely current limited. In contrast, solid-state amplifiers are voltage limited. Below is a grid that displays the peak current, voltage, and wattage relationships for an 8 ohm load:

Amps	Watts	Volts
.5	1	4
1	4	8
2	16	16
3	32	24
4	64	32
5	100	40
6	144	48
8	256	64

Current, voltage, and wattage Relationships for an 8 ohm load

Since a Class-A, push-pull amplifier can put out twice its idle current, a 4 watt amplifier will require an idle current of 500 mA. Each 6AS7 triode can safely be run with both a plate voltage of 110 volts and a idle current of 100 mA (11 watts of dissipation per triode). Thus, ten 6AS7 triodes would be needed per channel (five 6AS7 envelopes). This number does not change with push-pull topology; either the Circlotron or the totem pole arrangement requires ten 6AS7 triodes. The output impedance depends on the feedback topology, but in the absence of feedback, 9 ohms is my guess.

If these tubes are allowed to go into Class-AB operation, 16 watts will be delivered into an 8 ohm load. Why so few watts? The high idle current subtracts from the potential watts, as the onset of positive grid voltage defines a limit for the grid's excursions and the greater the idle current, the closer we come to that limit. If you are willing to live with grid current conduction, the potential wattage radically increases, as does the likelihood of tube failure and increased distortion. The following screen capture displays the composite plate curves for 5 parallel 6AS7s triodes. Even with this high idle current, some non-linearity is readily seen.



A better choice might the EL509. This tube is available from Svetlana (yes, I know that the American portion of the company is kaput, but I understand that the Russian company continues). It is used in the Transcendent OTL amplifiers. Using eight EL509s yields 80 watts, which translates into a little over 1A peak current per tube. Therefore, two EL509s in a push-pull should easily give us our 4 watt output, if we retain the plate voltages used in the 80 watt version. Notice that quartered the output stage and reduced the output by sixteen-fold.

In the next issue, we go over a possible design of a 4 watt OTL that uses two of these tubes. Until then let's hope that someone can send in a set of triode plate curves for this tube.

Subject: Hybrid Amplifier

Thanks for the interesting article on Hybrid Amplifiers. I have owned many amps over the years, tube and solid state, and feel that the hybrid may be the best of all available designs. Attached is the Hybrid that I'm currently building.

The tube is a 7370 which is a 5687 with a 40 volt heater so it can be fed with the negative 40 volt rail. This keeps the heater to cathode voltage within limits and eliminates the need for a separate filament supply. The tube rails are provided by positive and negative voltage triplers for +/- 120 volts.

The totem resistors are 210 ohms each bypassed with 200 µF minimum for 20 mA of idle current. It can provide up to 40 mA.

The BUZ900/905 are Magnatek equivalents of the 2SK150/J50 series lateral MOSFETs with a true negative temperature coefficient so no compensation is needed. Two devices are paralleled for greater current.

This is the simplest 100 watt Hybrid design that I could come up with that uses no feedback and can provide low distortion if the MOSFET pair is idled at 500 ma. Any comments on this design would be appreciated.

Dave
Somewhere in the American Midwest

The reply to Dave's e-mail is the article on hybrid amplifiers in this issue.

Subject: oscilloscope

Do you know of software for PC to use it as an oscilloscope? I have enjoyed your articles very much. Thanks for all the hard work.

Gonzo.
USA

One advantage to these units is that they perform spectrum analysis on the waveforms. I own, but seldom use a Velleman PCS64i PC oscilloscope (I bought it so that I could provide screen captures of waveforms for this journal). Do not get me wrong, this is a fine unit, which I recommend to anyone who has need for such a instrument. The reason I seldom use it is that my PC is too far away from my workbench and that I am very comfortable with my old oscilloscope (and somewhat uncomfortable with the idea of high voltage meeting my computer, even though the PC scope is fully isolated).

I recommend a Google search for other similar scopes.

Subject: Multi-channel audio

With the advent of home theater systems for DVD's I notice a high price and high power. Nothing in the LOW price and the SMALL apartment sized systems. Umm. Bookcase size for my tiny loving room. Is the Home theater solely the domain of solid state and custom computer logic or can a home grown tube design fit in nicely that is of low and medium power?

Ben.

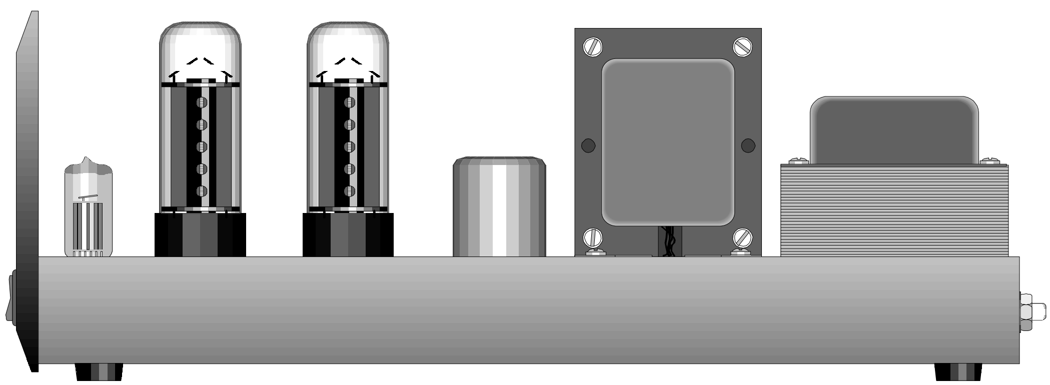
?

For years I have been trying to convince tube related companies to come out with a high quality five channel tube amplifier; in vain. In general, tube watts sound more powerful than solid-state watts. So five 30 watt amplifiers should fill the bill, especially if solid-state powered sub-woofers are used.

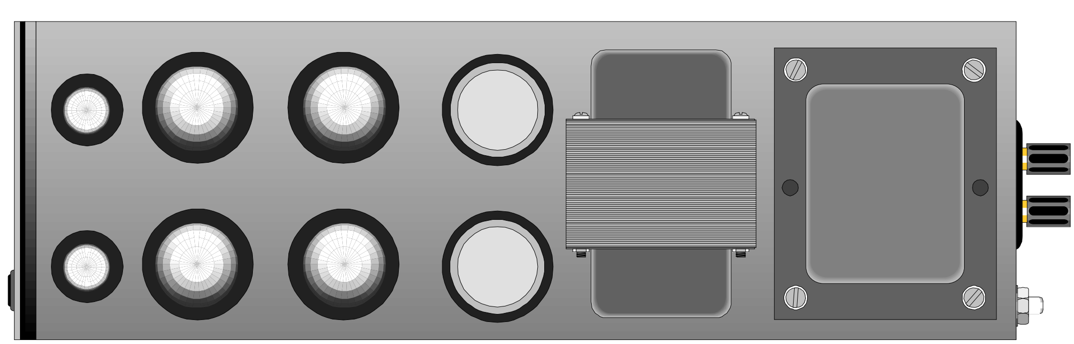
The pitch I made was to build very slender mono-block amplifiers that could be bought separately. Thus if someone only wanted a pair of 30 watt Class-A amplifiers, they would buy two. If they later want to bi-amp, they buy another pair. Or if they want a five channel amplifier, they buy five. The faceplate could be made from an anodized extrusion and it would serve to protect the output tubes, eliminating the need for a cage. A nice touch would be to bore a large hole in the faceplate, allowing a view of the tubes.

As for the decoding boxes, a market exist for a tube output based unit. Why does no one come out with it? Bytheway, a poor man's five channel system can be made from one stereo transformer coupled amplifier and five speakers and two high-wattage resistors. At first, you may not immediately like the sound, finding it too big sounding, but after a day or two, the two-speaker alternative will sound small, flat, and thin by comparison.

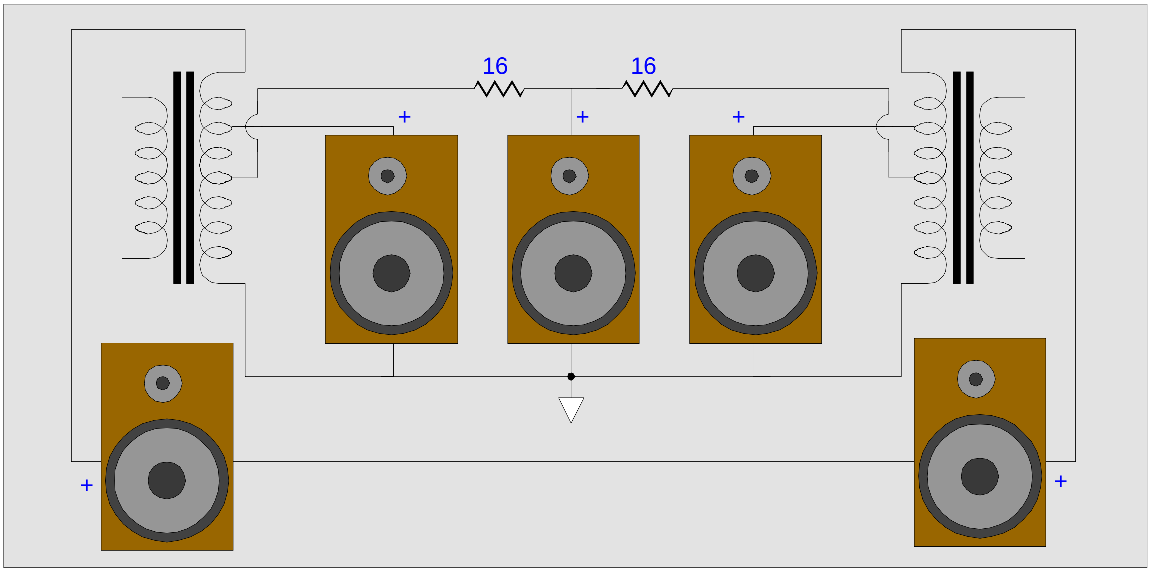
Side view



Top view



Poor man's surround-sound system



Subject: tube circuits

I have got a question about a possible circuit that I have been tossing around in my head for awhile now. This involves the use of tubes in a hybrid, tube-IC, surround sound processor. I know that some commercial processors are based on the PMI 2126SA , IC for pro-logic surround. Shouldn't it be possible to utilize some of that circuitry along with tube circuitry (especially differential amp circuits) to produce a simple but fantastic sounding surround sound processor? I would be interested in your thoughts on this.

Cal
USA

Bless you. I knew that such a circuit must exist, but I did not want to find it. Using this IC and a tubes could make for a sweet sounding setup. I bought a Dolby surround processor over ten years ago. I listened to it for a little over one month and then put it in closet where it remains. The effects were impressive, but the sound was as bad as is found in movie theaters, harsh and brittle. I will look into this chip and see what can wrested from it.

Subject: auto bias in a cathode follower

I read with great interest your articles about automatically regulating bias in a common cathode circuit using a small voltage sensing resistor in the cathode. I was wondering if this could be transferred to a cathode follower design? I am trying to make a cathode follower with a constant current source on the cathode. I want the output of the CF at 0v which would be at the top of the CCS and the bottom of the voltage sense resistor. Is there a way of using your automatic fixed bias circuits to really lock in the cathode current of a CF with the constant current source on the cathode? I am aiming to use a pentode as the CF.

Richard
?

Check out the circuit at the GlassWare Tube Circuit of the Month web site. It makes use of what I call a compliant current source. It meets the quiescent current presented to it, rather than proscribing a fixed amount. As the tube heats up or ages, the circuit matches its idle current. Furthermore, at the same time that it presents a near infinite impedance to audio frequency, it works to maintain an output referenced to ground.

Subject: Triode-connected beam tetrodes?

What happens to the operational characteristics of a pair of 6L6 beam pentodes (push-pull, Class-AB1) when their screen voltage is slowly brought up to equal the plate voltage?

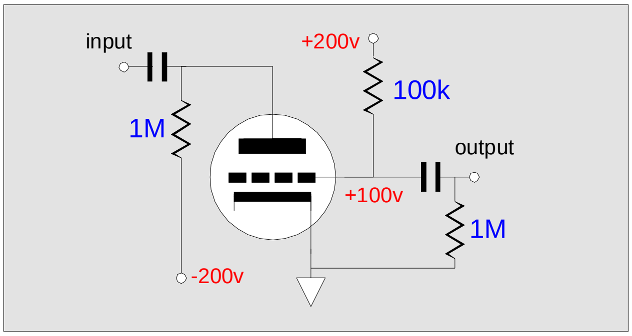
Does the power supply choke (or ripple-reducing resistor) provide sufficient feedback (or, conversely, isolation) to cause the tubes to "behave" more like triodes than pentodes? Would the amplification factor, mu, decline from 171.6 down to 7.99; the transconductance, gm, lower from 0.0052 S to

0.0047 S; and, would the plate resistance, rp, fall from 33K down to 1.7K? In short, as the screen and plate voltages converged, the tubes would gradually assume the triode operational characteristics?

Earles
Tucson, AZ, USA.

Both the grid and screen control the current conduction in a tetrode or pentode. The grid exercises more control than the screen, so it can be said to have greater amplification factor. In other words, ±1 volts of signal at the grid might require ±10 volts of signal at the screen to equal the same change in current flow. The plate also exercises a control over the tube's conduction. The plate, however, is only 1/mu times as effective as the grid. In fact, the screen can be used as the output terminal and the plate can be used as the controlling element, albeit with a greatly reduced gain and dissipation limit. Even with the triode, the grid can be attached to the load resistor and the plate becomes the effective "grid."

This information is not meant to be practical, only informative. The thing to remember is that both the triode and the pentode are really modified diodes. The cathode emits electrons, which the plate receives when it is more positive than the cathode. If the plate is made negative to cathode, it stop receiving electrons, but it does not cease to have an effect on the flow of electrons from cathode to a positive charged grid. In this case, we still have a triode like function, but with reordered roles.



I have long desired to build a line stage or power amplifier that used a grid-amplifier, as this topology has been called. My motive is not better sound, but the potential for baffling a few tube gurus I know.

The greater the voltage on grid, the screen, or the plate, the greater the conduction. Connecting the screen to the grid, makes for a super high mu triode that can barely conduct at all. Connecting the screen to the plate, makes for a low mu triode with a low rp. Connecting the grid to the cathode and using the screen as the control element, makes for a low mu triode with a high rp. It is the connections that matter most. Having the plate and the screen share the same DC voltage does not make a triode out of the pentode. AC connecting the screen to the plate does make a triode.

The connection may only be partial, as it is an ultra-linear amplifier. Here the screen receives only a portion of the AC signal at the plate. The greater the percentage of plate signal, the closer the tube comes being a triode. Conversely, the less the percentage, the closer to being a pentode.

Subject: Medium Gain Line Stage Amplifier (sep 1998)

First I would like to thank you for your excellent web-magazine. Because of your comprehensible written articles, I am able to learn with every article.

I would like to build your design for a medium gain line stage amplifier (September 1998). But there is a small problem. The design with the 12BH7 seems perfect with just the right amount of amplification, but it is not that easy to find those tubes in the Netherlands.

I would like to you use the ECC82 instead of the 12BH7, the ratings of the ECC82 look rather similar to the 12BH7. But having learned a lot form your articles, I am still not able to calculate the right values.

Could you help me with the right values or perhaps with the right formulas so I can calculate these values myself? (I also need to know the right wattage for the resistors.)

Luuk
The Netherlands

The ECC82, AKA 12AU7, is definitely usable, although I prefer to use a more robust tube. if we retain the same B+ voltage of 300 volts, the plate and cathode load resistors should be increased to 20k and the bias resistor should be 562.

While there is a formula that gives us the cathode resistor value, it is based on the assumption that the triode is perfectly linear. It isn't. The best plan is to review the plate curves and find where the grid intersects with desired plate voltage and idle current.

Once the grid voltage is known, it is divided by the idle current and the result is the cathode resistor value. The general rule with resistor is to use a resistor wattage twice as great as is needed. For example, if the plate resistor will see 150 volts across its leads and current conduction of 5 mA, then it will dissipate .75 watts of heat; thus, using a 1.5 to 2 watt resistor would be wise.

Subject: Headphone Amplifier Inquiry

Sorry to bother you, but I have no one in my area to ask. I am trying to work out a headphone amplifier design, based on an old RCA microphone preamplifier. It is wonderfully simple, and seems to make running one tube a side a possibility. Problem is, high impedance on the output - 220k Z is what the RCA design says. (This is with a 12AX7. I am likely to substitute another tube which will bring the impedance down some, but it is still likely to be high.) I'd like to use this Preamp. to drive my 250 ohm headphones. So am thinking of using an impedance matching transformer on each side. Problem I foresee is a large step-down: ~220K to 250 ohms. That's near "1000 to one" for the transformer! I've been looking around for such a transformer, and I haven't found it yet. So am thinking of winding my own.

Do you believe this feasible? Any ideas/opinions/ suggestions welcomed.

Not having seen the schematic, I can only guess what is going on (i.e. please send a copy). It sounds like the circuit is only a grounded cathode amplifier that uses a 12AX7. The 12AX7 does provide a good deal of gain, but very little power. An optimally designed resistor loaded single-ended amplifier delivers only 12.5 % of its power dissipation into the load. In other words, even with a coupling transformer, the power output may be insufficient. A better choice might be the 12AT7, as it has a lower rp and healthy amount of gain.

The impedance matching transformer winding ratio is the output impedance divided by the input impedance, that result is the impedance ratio. The winding ratio is the same as the voltage ratio (and current ratio as well), which is the square root of the impedance ratio. Therefore, the winding ratio you need is only 32 to 1. The big problem with coupling transformers is not finding the right winding ratio, but finding a high quality one.

Subject: Article Request "UltraPath"

Maybe you could write an article about the Western Electric "UltraPath" circuit and it's variant forms. How it works, how to properly apply it, where are its applications. There's another method where you use a capacitor from B+ to cathode that forms a voltage divider with the cathode bypass capacitor and achieves B+ supply noise and hum cancellation as well as improves PSRR. This can be applied to any cathode biased stage with a resistor. Not sure how it can help a battery biased or zener biased cathode. There's actually a lot to this interesting topic and has been discussed by me on audioasylum.com. It would be nice to see your treatment of the subject and have it summarized concisely in an article. One application that seems to work, but it's not intuitive, has been for push-pull stages.

Kurt

The blame for the "UltraPath" topology does not belong to WE, or at least I am not aware of it doing so; I am not sure who first started using it; in fact, one reader wrote that it was John Atwood's creation. It isn't. Here was my reply:

> As for the Ultrapath circuit, the blame does not belong to John Atwood, as I believe it is from Jack Elliano of Electra-Print. I have heard good reviews of his amplifiers and transformers, but I am sure that it does hum, you see it is only half wrong, or rather, half right. The complete UltraUltrapath circuit is covered in the second issue of this journal in an article titled “Lowering the Single Ended Amplifier's Output Noise.”
> http://www.tubecad.com/april99

This article might even predate Jack's article in *VTV*, but I do not care much about its history (and even less for the name...maybe from now on I will name all the circuits in this journal with whimsical names such as the “Gray Dove” preamp or the “Defiant Follower” or the “MegaFlow” voltage regulator) as much as I care about its purpose and functioning. And I can see why it is so hot a topic, as it is so simple: the power supply capacitor use go to ground, now it goes to the cathode; too simple.

In contrast, the two cap solution I offered in the article, ladened with theory, math, illustrations, and explanations, is next to worthless compared to move capacitor's terminating point. Why? How? Remember Whitehead's dictum:

"Seek simplicity and distrust it."

And while we are at it, Henry Adams observation on simplicity:

"The most deceitful mistress that ever betrayed man."

And of course, Einstein's famous remark:

"Make everything as simple as possible, but not simpler."

The "UltraPath" is too simple. In the article on hybrids in this issue there is the case where the power supply noise was reduced by connecting the bypass capacitor to ground and not the power supply rail. "UltraPathing" this circuit would increase the noise at the output. Furthermore, the output stage does not exist in a vacuum; the previous stages bring their own noise problems.

I have helped friends implement the noise canceling tricks from April and May 99 articles. They now call me, bubbling with enthusiasm, asking if I could "Ultra Path" their single-ended amplifiers for them. When told that for over half a decade their amplifiers all ready had a complete and true implementation of the "UltraPath," their ardor was dampened, not eliminated. "But this is something new," they complained. The name is new. The name seduces. I can imagine some enterprising fellow renaming and re-labeling the 6550 pentode, let's say the "Ultra Plate" for example. Then I will get calls asking for help to replace the WE 300Bs with "Ultra Plates." Maybe I am wrong and Proust was right: renaming, recreates.

Surely, our aim is a quiet amplifier. Achieving that aim is possible from two approaches. The first is the way of the brute force: large chokes, large filter capacitors, and voltage regulation. The second is the way of canceling the noise by artful noise injection, balancing, and nulling. This last approach is not one single topology, but rather a family of techniques and stratagems. The problem is that this practice lacks a name. As Nietzsche pointed out "As people are usually constituted, it is the name that first makes a thing generally visible to them." So here is a name: "Audio Aikido." Like Aikido, force is not met with force, but instead the force is used against itself;

Subject: misc. notes

Hi JRB (John, I think). I am writing to say I VERY MUCH enjoy your webzine and to offer a few suggestions.

First suggestion: in your latest issue, page 20, the reality check headphone amp, I suggest using either an LM833 or LM837 instead of the LF157. The first is a dual Op-Amp, the second a quad. These are both intended to be audio amps. In fact, each section of the LM837 is intended to drive a 600 ohm load, and will drive +/- 40 mA. So in parallel one IC could drive 150 ohms to "full output" meaning within a couple volts of the rails. It would probably drive fewer ohms if you did not need as many volts p-p. Or you could parallel several ICs and drive (at least some) headphones directly with the ICs and skip the output transistors. The LM837s are less than $2 each from Digi-Key. The LM833s just over $1.

Second suggestion: in the same headphone amp, I suggest that the resistor connected to the base of the lower transistor have its upper end connected to the + 7.2 V bus.

Third, in a later article in the issue, instead of using the IRF series MOSFETs use Hitachi 2SK1056,7,or 8 for the N channels, and 2SJ160,1, or 2 for the P channels. These are rated at 100 watts each and are *intended* to be used as audio amps. (What a concept!) NOTE: the pin outs are different than the IRFs. The gate is in the same place, but the source and drain are reversed. I have a set of the N channels in a Nelson Pass Zen type amp and they sound great. (My opinion, of course) Hitachi also makes some 125 watt units but their data sheets and P/Ns are hiding from me at the minute. Hitachi also makes some lower power FETs 2SK213,4,5, and 6 N channels and 2SJ76,7,8, and 9 P channels. I humbly suggest these N channels in place of the BJTs in the headphone amp mentioned above. But I admit I am a "FET-head". (I am off line as I write this and I think you mentioned some other Hitachi FETs which I think are no longer made.) Yeah, I know, *TUBE Cad Journal*. I'll get out of the sand box.

Fourth suggestion: As you know, the RIAA equalization curve has two parts, one above and one below about 2 KHz. I suggest incorporating the part above 2 KHz into the feedback circuitry in or around the output stage. Thus for frequencies above 2 KHz any harmonics or noise generated get more feedback (and attenuation) than the fundamental. This feedback might be in the form of an inductor in series with the cathode. This idea is not original, but taken from "other" circuitry.

Briefly: as a teenager in the early 60's I built tube amps. 12AX7s, 6L6s and the like were some of my "best" childhood friends. In the late 60's I went on to BJT amps. In the 80's moved to FET amps and a couple years ago became a self proclaimed follower of Nelson Pass and his minimalist ways. So I AM NOT KNOCKING TUBES! I greatly enjoy your analysis of circuits and marvel at your ability to come up with new ones, or at least ones I have not seen before. Keep up the great work!!

Jim (Colorado)

Jim, thanks for the suggestions. The reality check headphone amplifier was not meant to be a definitive solid-state headphone amplifier, rather it was presented as a good-sounding cheap alternative to an expensive and complex tube circuit. If the tube circuit failed to beat the Op-Amp, why bother?

Were I to design a definitive solid-state headphone amplifier, it would be based on discrete, hand picked transistors or MOSFETs. Or possibly, it would consist of only a LH0033 zero feedback buffer with a DC servo, battery power supply, and a healthy idle current.

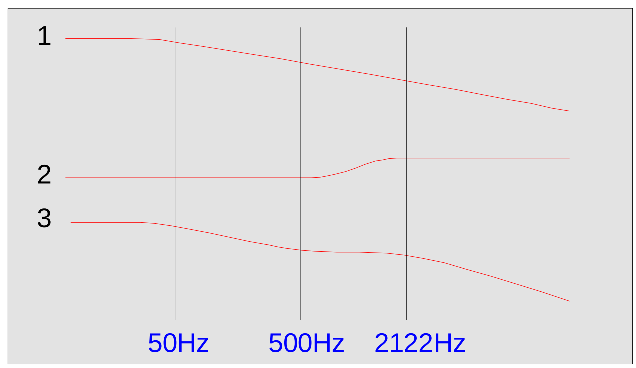
I expected at least one e-mail concerning the resistor connected to the output of the Op-Amp in the reality check headphone amplifier. This resistor serves two purposes: the first is to provide a bias current for the IC voltage reference and the second is to shunt out half of the Op-Amp's output transistors and force the Op-Amp output stage to work as single-ended Class-A amplifier. Most Op-Amps run a miniscule idle current through their output transistors, so only a small amount of unilateral current drag will shut off half of the output stage. The remaining "on" transistor now must counter the tug towards the negative rail by pulling the output to ground level. Thus, by placing the resistor between output and voltage reference, both goals were achieved.

Thanks for the tips on the MOSFETs. The headphone amplifier used a transistor because it makes for a greater output voltage swing, as the transistor only needs to see a .7 volt base-to-emitter difference to conduct; the MOSFET, 3 to 4 volts.

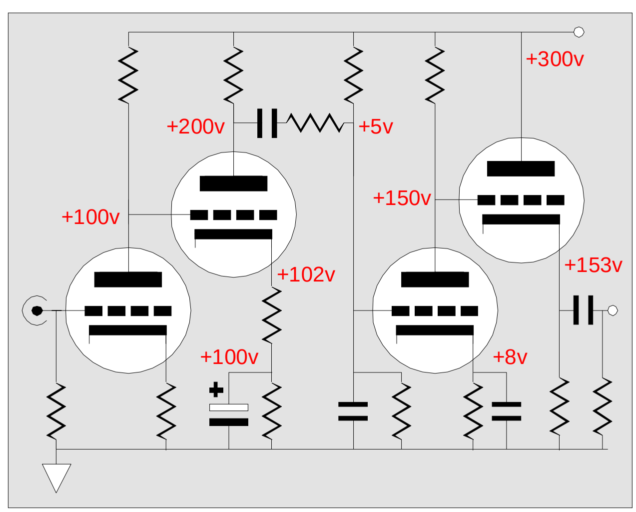
The RIAA EQ curve can be realized by many topologies. However, using a choke in place of a cathode resistor will set in place a 6 dB per octave low pass filter. Unfortunately, the output impedance at the plate will climb with increasing frequency and with this climb the PSRR will drop, adding more noise to the output.

One trick might be to only bypass the cathode resistor with a small valued capacitor. This capacitor will result in a skewed frequency response: flat up to the transition frequency, then a 6 dB climb to some breaking frequency, and flat thereafter. In other words, a high frequency booster, much like a tone control would impose. Wait a minute, doesn't that run counter to the required RIAA EQ curvature? Yes, it does. But if we impose a low pass filter centered on the 50 Hz point of the curve first, then the boost will then cancel the a portion of the decline and the final curve will achieve the desired RIAA EQ. The following circuit gives a rough idea of how to implement it.

Editor
Energy Free California



RIAA EQ curve (3) achieved by adding curve 1 to curve 2



Possible implementation of this idea

Moving about in the Tube CAD Journal

Tube CAD Journal Publishing

Our Purpose

The ***Tube CAD Journal*** is a monthly online magazine devoted to tube audio circuit design. Each month we will present some fresh looks at some old tube circuits and some altogether fresh tube circuits as well (yes, new tube circuits are possible). Circuits and more circuits. While we plan on covering complex tube circuits, like phono preamps or power amplifiers, our focus will be primarily on elemental circuits. Elemental circuits are the primary topologies, or part configurations, arrangements that can stand on their own as recognizable functional circuits although they may be part of a larger circuit. A power amplifier circuit, such as the famous Williamson, comprises several sub-circuits: the Grounded Cathode amplifier, the Split-Load phase splitter, the Differential amplifier and finally a push-pull output stage. Just as we must understand how a resistor or a capacitor functions in a simple circuit, we must understand the function and logic of these elemental circuits before we can understand more complex compound circuits.

Why a Webzine?

The original intent was to print a conventional magazine. We knew there was a need. A query on our Tube CAD registration cards that a magazine devoted to tube circuit design drew an overwhelmingly loud "YES." Still, we knew the difficulty and impracticality of starting yet another underground tube audio magazine.

The Web offers the publisher some great advantages over the traditional approach: worldwide distribution, free subscriptions, no paper (for those who must own a paper version, the size of the journal has been left small enough to be printed on A4 or 8.5" by 11" three-hole punched paper for compilation in a three-ring binder), live forums, no Post Office, color, motion, a glossary.

Schematics can now evolve, as the web allows for the easy display of animated GIF's, which display color and motion. Schematics can now show more than just part connections, they can reveal voltage potentials, current flow directions, and possibly, relative impedances.

Math errors and typos will not live indefinitely on a paper page; once spotted, the Web page can be corrected quickly.

We look forward to your letters, suggestions and contributions.

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