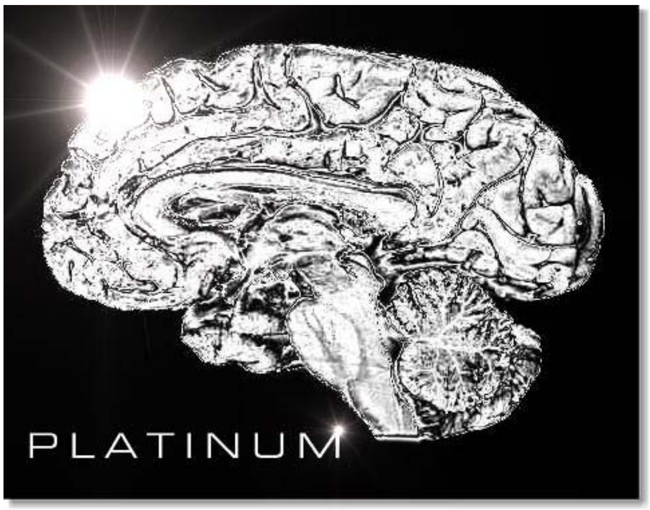
TUBE CAD JOURNAL

This Issue



The Triode Guild scoops the MacArthur Foundation and awards your humble editor the coveted Platinum Brain Award for my contributions to the thermionic arts. I am deeply honored and my only qualm is that I am not sure whether I must donate my brain to medical research after or before my death.

Tube based shunt regulators and tube headphone amplifiers are this issue's focus. Next issue we will revive a lost output topology.

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

Editor

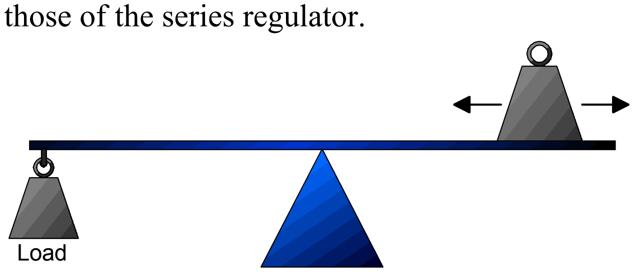
In This Issue

Inverted Shunt Regulator

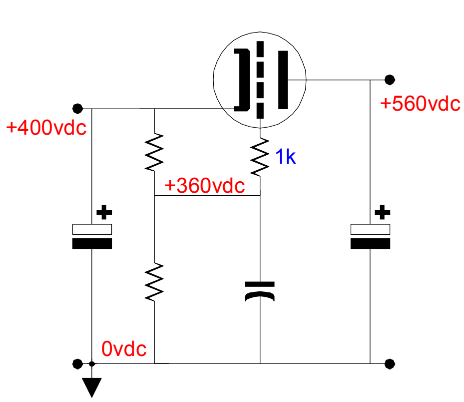
The shunt regulator is making a stir in tube world, but details on its design and use are few and hard to find. This regulator topology was usually used in low-current, high-voltage applications, such as TV 30 kV power supplies. Thus, since this regulator was not used extensively even during the glory day of tube dominance, we must blaze our own trails, which might be a blessing in disguise, as the past practices often shackle rather than just inform.

First let's start with a an overview. Both the series and the shunt regulator share about the same number of parts. And they share the same basic goals and functioning: a constant output voltage achieved by actively comparing the output to a voltage reference and adjusting the conduction through an active device such as a tube or transistor to bring that output inline with the reference voltage regardless of variation the wall voltage or variation in the current being drawn at the regulator's output.

How they differ lies in how the components are arranged. The defining difference between shunt and series regulators rests in that the active element, the pass or losser device, works in parallel with the load, rather than in series with it. Yet this seemingly simple topological rearrangement alters radically the shunt regulators operational considerations versus those of the series regulator.



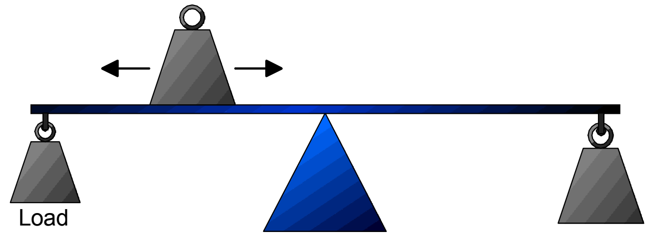
Mechanical analogy of series regulator



Simple AC only series regulator

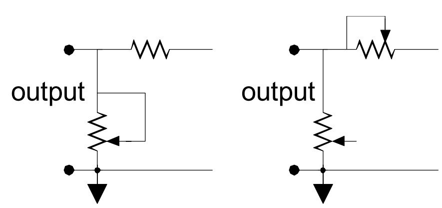
One way of looking at the series regulator is that its pass device effectively presents a variable resistance to the power supply. Thus the series regulator's active device can be likened to a potentiometer in series with a load. If the load is simply a resistor, then the goal is simple: maintain a constant voltage across the resistor in spite of fluctuations in the power supply voltage. As the wall voltage rises and falls, and as the power supply's rectifying of the AC creates ripple, the potentiometer's wiper is correspondingly adjusted to cancel any voltage perturbations from appearing across the resistor. As the power supply voltage climbs, the potentiometer's resistance increases; when the voltage falls, it decreases. With only a resistor load, the result of this varying resistance is that load sees a zero-impedance, fixed voltage and the power supply sees effectively a fixed current draw, i.e. constant current source.

On the other hand, if the load is a Class B amplifier, then in terms of voltage, the goal remains the same: maintain a constant voltage across the amplifier. But in terms of current, the amplifier will draw a varying current. In other words, while the amplifier will see a constant voltage, the power supply will see a wildly varying current draw as the amplifier draws a varying amount of current: almost none at idle and many amps of current draw at full output. Now the regulator functions more like a current mirror, reflecting all the current variations back into the power supply.



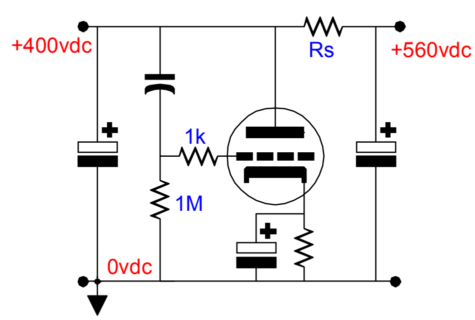
Mechanical analogy of shunt regulator

Now, lets turn the schematic sideways and look at the shunt regulator. The shunt regulator can be likened to a potentiometer in parallel with a load, both of which are placed in series with a fixed resistor. The goal remains the same as before: maintain a constant voltage across the load. Just as before, as the wall voltage rises and falls and the power supply creates ripple, the potentiometer wiper is correspondingly twisted to cancel any voltage perturbations from appearing across the resistor. The twisting must occur in anti-phase with the potentiometer in the series regulator example: as the power supply voltage climbs, the potentiometer's resistance decreases; when the voltage falls, it increases.



Potentiometer analogy of
shunt and series regulators

The load sees a fixed voltage and the power supply effectively sees not a current source as in the series regulator example, but only a fixed resistance, i.e. the series resistor's resistance. Regardless whether the load is a simple resistor or Class B amplifier, the potentiometer's varying



Simple AC only shunt regulator

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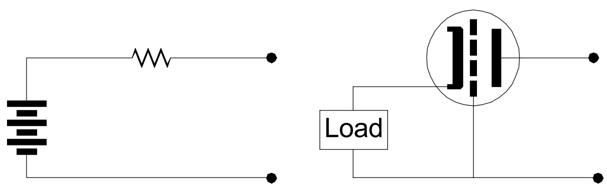
resistance, in parallel with a load that draws a constant or varying amount of current, creates a battery like effect of zero ohms termination for the load and the series resistor. In other words, while the load can be as wildly varying as a Class B amplifier, the power supply *will not* see a wildly varying current draw even as the amplifier draws a varying amount of current.



The power supply's view of shunt and series regulators

This situation is vastly different from the that of the series regulator and, in many ways, preferred. It is as if the current variations produced by the regulator's load are trapped on the load's side of the series resistor, preventing those current variations from re-circulating into the power supply and from there into other circuits and stages.

This benefit of increased isolation comes at the cost of a much greater quiescent idle current for the shunt regulator. For example, if the load is a Class B amplifier that has a current draw of 10 ma to 4 amps, then the shunt regulator's idle current would have to at least equal 4 amps! (And if we wish to cover a wide range of wall voltage variation, the idle current might have to be set to 6 amps. In this case the series resistor really should be replaced by a current source. And the argument can be made that in all cases, the shunt regulator should only use a current source, rather than the resistor; or in the case where our only concern is AC regulation, not DC, the resistor should be replaced by a choke.)

When the shunt regulator faces an amplifier idling at only 10 mA, the active shunting tube or solid-state device will have to draw 3.99 amps; when the amplifier draws 4 amps, shunting device will have to draw zero current. Compare this hefty idle current demands to that of a series regulator with the same load: as little as 15 mA at idle and 4.005 amps at the other extreme. With savings such as these is it any wonder that series regulator predominates.

However, when the load draws a constant current rather than a varying current, both the series and shunt regulator can use a lower wattage active device. In the case of the series regulator, a high wattage resistor can be placed in parallel with the pass device. This resistor would provide the larger portion of the current flowing into the load and the pass device would have the task of fine tuning the output. Or, in the case of the shunt regulator, the shunting device can be scaled back in terms of dissipation, as it would only have compensate for the small straying from the reference voltage due to ripple. For example, if the load is a Class A amplifier that draws a constant current of 4 amps, the modified shunt regulator must maintain a total current draw at idle of slightly greater than 4 amps, let's say, 4.01 amps, which means the losser device would handle only the 10 mA of the total. Another example, if the load is an SE Class A amplifier tube amplifier that draws an idle current of 150 mA, which climbs to 155 mA at full output due to rectification effects, the delta equals only 5 mA. This difference could easily be handled by a single section of a 5687. You see the active shunting device only needs to cover the delta (the difference) in current fluctuations. In this example, the 5687 placed in parallel with the output tube, need only draw an idle current of 10 mA, 5 mA of which it will give up when the output stage's current draw increases by 5 mA.

Regulator Analogies

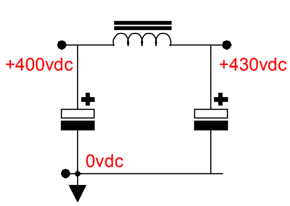
One way to look at the difference between the series and the shunt regulator is to view the series regulator as being analogous to a Class B amplifier and the shunt regulator as being analogous to a Class A amplifier. If the regulator is functioning as an amplifier, what is being amplified?

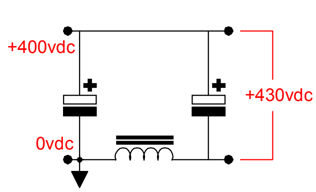
From this viewpoint, the ground is the *signal* and any deviation from that signal at the output is countered by the feedback until it is eliminated.

So which is better? Better for what? Better for needlessly heating the room? Better for using a battery power supply? Better for isolating delicate signal currents in an amplifier? Each finds its own place in tube audio designer's palette. My preference is to use kind for kind: a shunt regulator for steady average current draw circuits, for example Class A amplifier stages, and a series regulator for variable current draw circuits, for example Class AB, B output stages.

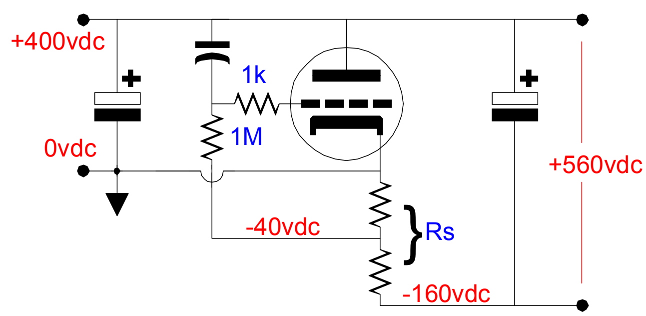
An Inverted Shunt Regulator

The usual topology is to place the series resistor in between the load and the B+ connection, just as a choke would normally be placed in a non-regulated power supply. However, just as the choke can be placed at the bottom, between load and negative power supply, the shunt regulator's series resistor can be placed at the bottom as well. What advantage can be wrestled from this inversion? In the case of the choke, the increased safety of moving the choke closer to ground stands out as a large advantage. With the choke at the top, its winding sees the full B+ voltage and should the wire's insulation breakdown, the voltage difference between the B+ voltage and the chokes ground level metal structure will make for some fireworks. But when the choke is placed at the bottom, the choke's winding and case only see the voltage developed across the DCR of the choke plus the ripple voltage, a total of 30 volts let's say. Now, the insulation should not breakdown and even if it did, 30 volts makes for much smaller sparks.





Placing the series resistor at the bottom also yields advantages. Some safety enhancement can be had from having one of the resistor's leads at ground potential and the other at much lower voltage than the top arranged series resistor. (Remember, voltage is analogous to velocity with moving objects, double the voltage or the velocity and wallop increase fourfold: kinetic Energy = $\frac{1}{2}MV^2$ and Joules = $\frac{1}{2}CV^2$. But the big advantage is that by referencing the ground at one of the resistor makes the other end a negative power supply. And negative power supplies are handy to have in tube equipment, but often difficult to create. For example, a power amplifier's output stage might need an negative power supply to bias the output tubes, but the high voltage transformer may not have a low or medium voltage tap.



Inverted shunt regulator

And when a transformer does have this tap, it is seldom matched with another tap on the other side of the center tap, which means that only a half-wave rectifier circuit can be used. The problem with half-wave rectifier circuits is that they are useful only if a minuscule amount of current is drawn from them, as they yield much more ripple and much less current than the full-wave rectifier circuit. (Excessive current draw through the half-wave rectifier also tends to magnetize, i.e. saturate the power transformer's core, as the current is being only drawn in one direction through the power transformer secondary winding.) And the alternative, using a full-wave bridge rectifier circuit, yields too much negative voltage and usually precludes using tube rectifiers.

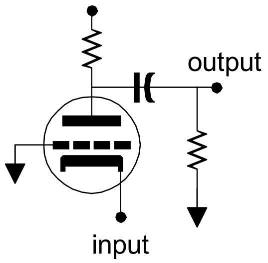
Moving the series resistor to the bottom does not alter the basic functioning of the shunt regulator. The output is still monitored for perturbations and active shunting device acts to counter those perturbations to yield a stable output voltage. Furthermore, because we now have a ready negative power supply, biasing the shunting tube becomes easy. All that is needed is a few additional resistors and a potentiometer. Additionally, the negative power supply is useful when setting up a zener diode string as a voltage reference, as the end of the zener string must be at the negative bias voltage of the shunting tube.

But the inverting the shunt regulator topology has at least one more advantage: the use of cathode resistor in the filtering of the power supply. In the conventional shunt regulator topology the cathode resistor is a liability, wasting heat and requiring an additional capacitor to shunt the cathode to ground. But in the inverted shunt regulator, this resistor is just part of series resistor, Resistors, total resistance. The cathode does not need a AC path to ground because it is the ground.

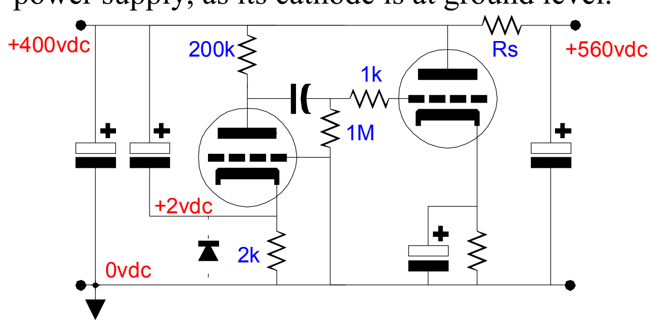
Grounded Grid Amplifier Shunt Regulator Front-End

One tube is seldom enough. Even the highest transconductance triode has a paltry amount of transconductance compared to a solid-state device, such as transistors or MOSFETs. And it is transconductance, *the change in current flow due to a change in grid-to-cathode voltage*, that powers a shunt regulator. Adding a first stage of voltage gain effectively boosts the Gm of the shunting tube by magnifying the error signal at the output. One stipulation is that the extra gain stage cannot invert the phase of the error signal, which leaves out the grounded cathode amplifier, but not the grounded grid amplifier. This circuit is a real sleeper: it does not invert the input signal phase and offers a wonderfully high-frequency bandwidth, as its grid shields the plate. The downside to this circuit is its very low input impedance: (Ra + rp) / (mu + 1).

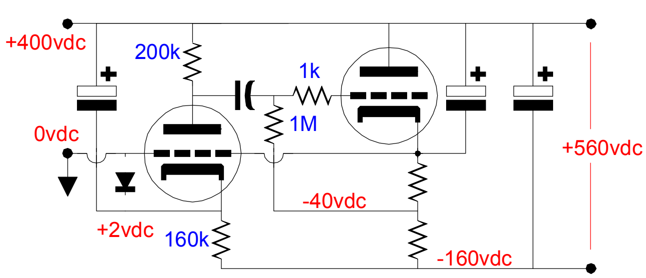
Grounded
grid amplifier



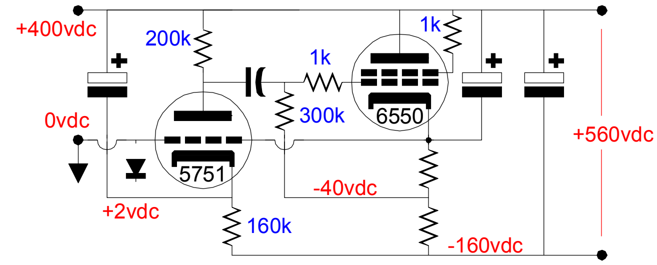
But the since the input signal is the noise at the power supply B+ connection, the power supply noise can be easily relayed to the cathode through a large valued electrolytic capacitor. And since the power supply noise frequency is twice the line frequency and since harmonics seldom extend beyond the 5th, exceptional high frequency transmission is not necessary. In fact, the usual disadvantage, power supply noise leaking into the output of the grounded grid or cathode amplifier, works in our favor in a shunt regulator circuit and against us in a comparable series regulator. Furthermore, the need to offer the pentode's screen grid a clean AC path to ground also disappears, as triode connecting the pentode works to increase the effectiveness of a shunting pentode tube. And do forget the advantage all tube shunt regulators share: the shunting tube's heater does not require a separate power supply, as its cathode is at ground level.



Grounded-grid front end shunt regulator



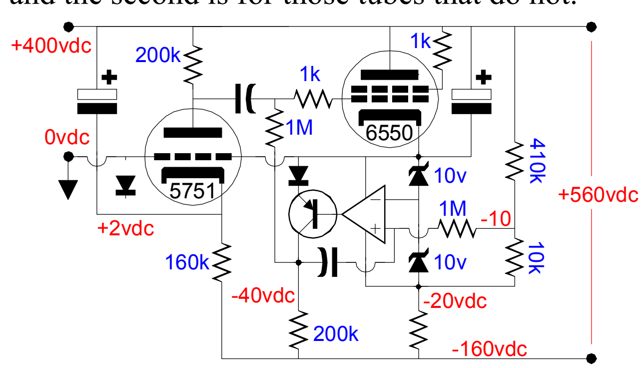
Grounded-grid front end inverted shunt regulator



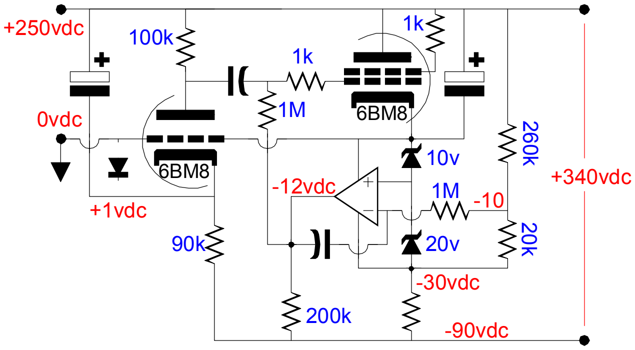
Grounded-grid front end for a
pentode based shunt regulator

The appearance of the diodes (connected by dashed lines) will have many readers scratching their heads. They are there as a safety measure; should the output accidentally short to ground, they will become forward biased when the capacitor that is connected to the grounded grid stage's cathode attempts to becomes a negative 400 voltage source. *Remember, always try to imagine the worst case scenario*.

We come this far, yet something is missing. So far all the examples have shown AC only shunt regulators. DC regulation can be implemented by paralleling the grounded grid stage's capacitor with a zener string and replacing the coupling capacitor to the shunting tube with a zener string that terminates into a resistor that leads to the negative power supply. Because this last arrangement will require much tweaking in construction and much adjustment in use, I would rather use an Op-Amp to adjust the DC portion of the regulator's output and let the tubes handle the AC portion where music falls. Two versions are shown below: the first is for shunting tubes that require a high negative bias and the second is for those tubes that do not.



DC and AC sensitive shunt regulator



Low bias DC and AC sensitive shunt regulator

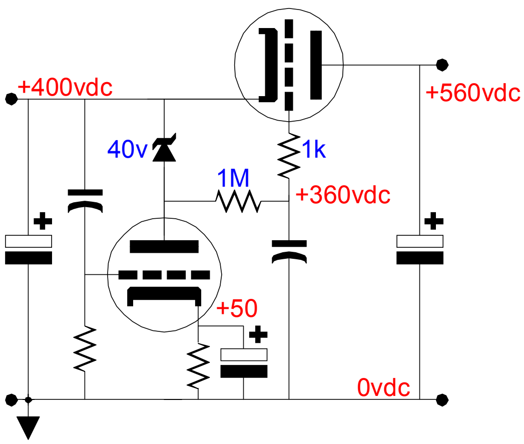
Other DC sensitive topologies are certainly possible. But in all shunt regulators the key points remain the same: the greater the transconductance of the shunting tube and the larger the value of the series resistor, the better the performance. Bear in mind the potentially destructive increase in current a DC sensitive shunting regulator face when assumptions fail to appear. For example, the wall voltage climbs or drops only 10% from its nominal value, or the load is removed while the regulator is in use. Given a raw DC power supply voltage of 560 volts, a Class AB power amplifier for a load that draws low of 120 mA and a high of 180 mA, a series resistor equal to 800 ohms, and a shunting tube that draws an average of 80 mA.

The math is simple enough: at idle, the entire regulator circuit including load draws 200 mA and dissipates 112 watts, as 200 mA times 560 volts equals 112 watts; the series resistor dissipates 32 watts, as 200 mA squared against 800 ohms equals 32 watts; the shunting tube at idle dissipates 32 watts, as 80 mA times 400 volts equals 32 watts. But if the wall voltage drops or climbs only 10%, the math looks quite different. A 10% increase in wall voltage equals a 48% increase the regulator's total dissipation and almost a 100% increase in shunting tube and series resistor dissipation. In stark contrast to the series regulator, the DC sensitive shunt regulator suffers when the load is removed. Where the series regulator is relieved by the load's departure, the shunt regulator burdened by the missing current draw that the shunting tube must supply. For example, if we use the shunt regulator from the last example, then we can rework the math. With the load that draws 120 mA of current, the shunting tube dissipates 32 watts at idle, but when the load is removed, it must dissipate 80 watts, as it must now draw the full 200 mA to bring the regulator's output voltage to 400 volts. Conversely and opposite to a series regulator, when the load's conduction increases, its dissipation drops.

Series Resistor Volts	Series Resistor mA	Series Resistor Watts	Shunting Tube Volts	Shunting Tube mA	Shunting Tube Watts	Regulator Total Watts	Raw B+ Voltage	Wall Voltage
104	130	13.5	400	10	4	65.5	504	90%
160	200	32	400	80	32	112	560	100%
216	270	58.3	400	150	60	166	616	110%

A Series-Shunt Regulator

Combining the series and the shunt regulator might prove the best compromise. The benefits from each type can be added together in one regulator. The series regulator half provides the compliant current sourcing that improves the efficiency and PSRR of the regulator and the shunt half of regulator provides the net current canceling function to keep load's current swings contained to the regulator. Putting both regulator together requires only a little imagination, as the regulator will look and function much like a totem pole push-pull amplifier.



Series-Shunt voltage regulator

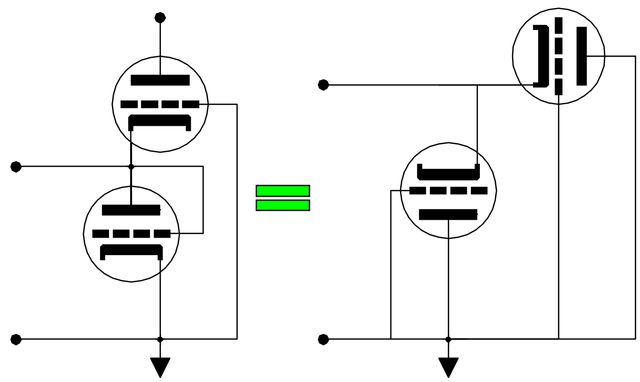
The regulator shown above relies on both tubes to counter any perturbations at the output of the regulator. The top tube functions as a cathode follower whose grid is AC grounded; the bottom tube functions as a grounded cathode amplifier with 100% feedback from the plate being applied to its grid. In effect what is created is two cathode followers, as the feedback given to the bottom tube yields the same performance as the top tube achieves as a cathode follower. Put analytically, a 1 volt pulse applied to the bottom triode's plate will be met with an increase in current flow through the triode equal to the 1 volt divided by the rp of the triode plus the transconductance of the triode times the 1 volt, which can be expressed as

$$I\Delta = 1 / rp + 1 \times Gm$$
$$I\Delta = 1 / rp + mu / rp$$
$$I\Delta = (1 + mu) / rp,$$

Which equals the absolute decrease in current the top triode experiences:

$$I\Delta = -1 / rp + -1 \times Gm$$
$$I\Delta = -1 / rp + -mu / rp$$
$$I\Delta = -(1 + mu) / rp.$$

In other words, 100% feedback from plate to grind in a grounded cathode amplifier make this amplifier function identically to a cathode follower, which also experiences 100% degenerative feedback.



Adding DC sensitivity to the regulator can accomplished by working on the top or the bottom triode's grid, but not both. Asides from extra complexity, it is not a good idea to have an internecine battle between both triodes over small reference voltage differences. The circuit below is one example of how DC correction could be added to the regulator (note the replacement of the zener by the plate resistor).

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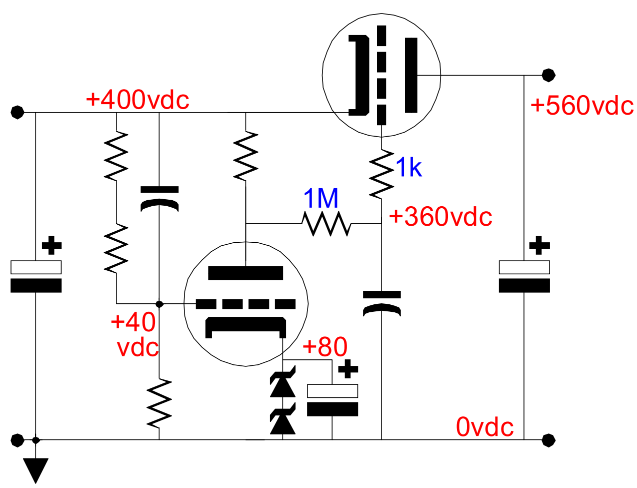
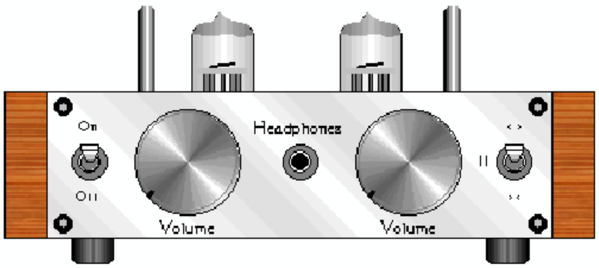
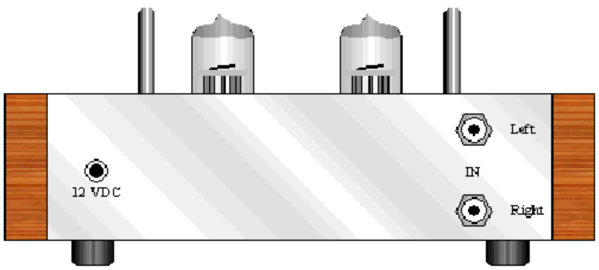


Portable Tube Headphone Amplifier (part 1)



Front of possible headphone amplifier



Back of possible headphone amplifier

In the last issue's letter section, I promised that in this issue we would begin covering the designing of a portable tube headphone amplifier for driving dynamic headphones. As always, this will be a more of a broad design example than a how-to-construction article, although in this case it will be a short a jump to finished amplifier by the next installment. First we need a goal and this time the goal is an amplifier that is small enough to fit in a backpack or briefcase, that is powered by either a wall wart transformer or a 12 volt battery, that is robust enough to drive headphones as low 32 ohms and as high as 300 ohms. Different goals are certainly possible, such as limiting the amplifier's size to that which would comfortably fit in a shirt pocket or driving electrostatic headphones. Different goals limit choices and results, but having a goal is as important as having a destination before packing for a trip, as it helps free us from ill-considered whimsies, such as the amplifier specifying that must use tube rectifiers and 300B output tubes.

Designing a portable tube headphone amplifier requires making many compromises. Large chokes and potted output transformers are out of consideration, as are large output tubes such as the 6C33 or 6AS7. In fact, even the 6BX7 or 5687 are out of the running because of their heavy heater current draw. Realistically, we must limit the size and power consumption of the amplifier, if we hope to make the amplifier portable and use a battery power source. Four 6DJ8s require almost 9 watts just to power the heaters; four 5687s, almost 23 watts. A strong AA type battery yields about 1.4 watts for one hour. Thus at least 7 cells would be needed just to heat four 6DJ8s for one hour. Additional cells would be needed to supply the B+ voltage.

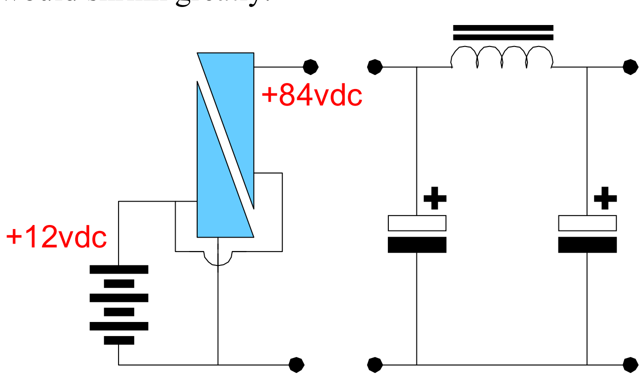
Battery Concerns

Several options present themselves when considering how to battery power the amplifier. We can use only batteries and no DC-DC converters. Impractical, yet elegant, what could be more hum free than a battery? This option would require four C or AA cells for the heaters and eight 9 volt cells in series to establish the B+ voltage. This assumes normal non-rechargeable batteries. Rechargeable batteries yield fewer volts: 1.2 for the single cells and 7.2 volts for the 9 volt package. Thus using rechargeable batteries would require five C or AA cells and ten "9 volt" batteries. Alternatively, we could use only "9 volt" batteries and use a DC-DC converter to step down the B+ to 6 volts for the heater supply.

The obstruction in this path is the losses in the DC conversion, since the heaters are the biggest power hogs in the amplifier. Well then, why not low voltage batteries for the heaters and step their voltage up to the B+ value with a DC-DC converter? This is probably the best path to follow, as it allows for the use of a low voltage lead-acid battery. Still new problem arise. Finding a DC-DC converters can be a headache. Off the shelf units are amazingly expensive and few in voltage increments. Designing a switching boost regulator is difficult and the results almost always require much tweaking.

Still, this last option is worth pursing, if you have the skill and time and patience. Fortunately, a maker of DC-DC converters, Newport Components, has come out with a two devices for phone equipment that offers 80% efficiency, 72 volts output from a 5 or a 12 volt source, 42 mA of current output, and a oscillator frequency of 85 kHz. The NMT1272SZ uses a 12 volt input and the NMT0572SZ, 5 volts. Both are packaged in an 8 pin SIP case and are wonderfully cheap, $15.00. If this sound too good to be true, it's because it is. The devices do not offer a tight regulation of the output voltage or a very low output noise voltage. The 12 volt version offer much better specs than the 5 volt version does, but it is still not close enough to what we need in a headphone amplifier.

Fortunately, the same tricks that work in a conventional power amplifier also work in a portable headphone amplifier, i.e. chokes and pi filters. The noise voltage equals 1.2 volts, which an output capacitor and choke and final capacitor would shrink greatly.



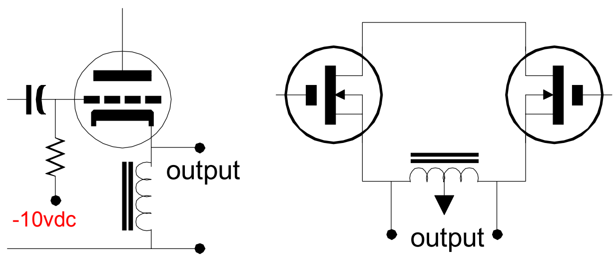
By using this DC-DC converter, a 12 volt power source, whether it be a battery or a wall wart, can feed the heaters directly and power one or two DC-to-DC converters. The output is isolated on these devices, so placing two outputs in series or parallel is possible. As is adding the input voltage to the output voltage to yield 84 volts of B+ or using the battery voltage for a negative power supply.

Now 84 volts may not seem like much, but it is enough to make a tube headphone amplifier possible. This low B+ voltage dictates that the output tubes must be able to draw a fairly high current at low plate voltages, which requires low rp, high perveance tubes, such as the 12B4, 6DJ8, 7111 or 6N1P. Yet the tubes must have a low heater current consumption: a catch 22 in the making. Thus fewer stages, thus fewer tubes are a better bet to lowering power consumption, which will limit the choices in circuit topology somewhat. In addition, the choice of output stage mode of operation must be addressed: Class B or A or AB?. Fortunately, here we get a break, as headphones require so little power that we can tolerate less efficiency; if we are repaid by better sound that is. Still, we should know how much efficiency we are giving up.

Modes of Operation

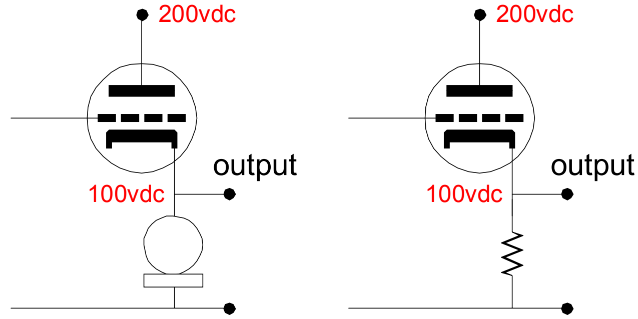
Class A output stages, whether push-pull or single-ended, strive to meat a theoretical limit of efficiency of 50%, where efficiency is defined as power delivered into the load divided by the power dissipated by the output stage. For example, if an amplifier's output stage consumes 100 watts and puts out 50 watts into a load, its efficiency would be 50%. Solid-state Class A amplifiers come close with efficiencies of up to 48%, pentodes usually fare worse, with efficiencies of only 25 to 40%, and triodes usually fare the worst, with efficiencies of only 10 to 35%. If the stipulation that the grid never enter grid current is removed (Class A2), then the efficiency of tube output stages can move closer to the 50% theoretical limit, but at the cost of a much more robust, higher-current driver stage.

All of this assumes transformer or inductive loading of an SE or a push-pull amplifier. Inductive loading means using an inductor (choke) to load the output device. Both tube and solid-state amplifiers, whether single-ended or push-pull, can be inductively loaded as long as they run in strict Class A. The inductor dissipates virtually no heat, yet provides a current source like functioning for audio frequencies. Furthermore the inductor does not subtract from the available B+ voltage as a current source would. You can readily see how brilliant a decision it was to use a inductive load so as to increase the efficiency of a Class A amplifier. But as very few amplifiers used today are Class A designs, the inductive load has almost been forgotten. (A big mistake.)



Inductive loaded amplifiers

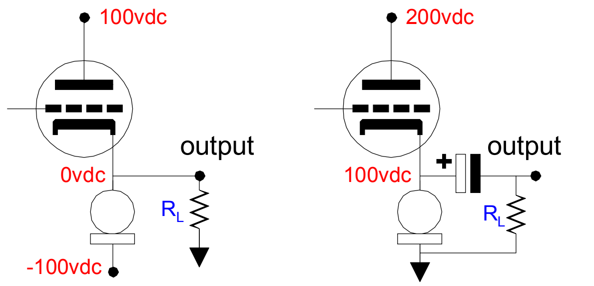
Resistor or current source loading, on the other hand, necessarily decreases the efficiency of the output stage, as the resistor or current source parasitically drag on the output stage, whereas, the transformer or inductive load displaces no voltage and gives back what current it takes. Remember a perfect transformer or inductor, like a perfect capacitor, dissipates no energy, as it see no voltage potential across its leads at idle. An inductor stressed by a DC current flow of 4 amps, gives up that 4 amps when unstressed. The resistor and the current source, on the other hand, do dissipate heat, as they do see both a voltage differential and a current flow at idle. In fact, the current source at idle must see all the voltage and current that the load will see at peak output, so that the current source can pull the load resistance to that peak when the active device nears cutoff.



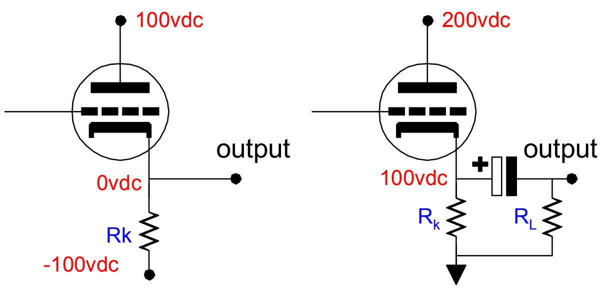
Current source and resistor loaded amplifiers

Consequently, we know that the active device, at idle, so as to match the current source, must also see all the voltage and current that the load will see at peak output. Thus, the maximum theoretical efficiency of a optimally designed current source loaded Class A amplifier is half that of the inductive loaded amplifier: only 25%. For example, delivering 2 amps into a speaker requires that current source and tube draw 2 amps at idle. So that when the tube approaches cutoff the current source can provide 2 amps into the load. And the tube must draw peaks of 4 amps so that it can over come 2 amps from the current source and deliver 2 amps into the load impedance. If the B+ voltage is 32 volts, the total dissipation of the amplifier's output stage comes in at 64 watts, which when divided into the 16 watts RMS that is given into the speaker, equals 25%. This example assumes the active devices are themselves perfectly efficient; they aren't.

With the resistor loaded output stage, the efficiency is even worse. Normally, we are not much bothered by the low efficiency of a resistor loaded grounded cathode amplifier or cathode follower, as our aim is usually voltage amplification, not power delivery. But consider the woeful efficiency of an amplifier that dissipates 2 watts in the load resistor the tube (100 volts each at 10 mA), yet only delivers 1 mW into a load resistance (10 volts RMS into a 100k resistor). The recommended practice of specifying a plate resistor or cathode resistor one fifth the value of the load resistance means that maximum effective efficiency of that amplifier can only be on fifth of its theoretical maximum.



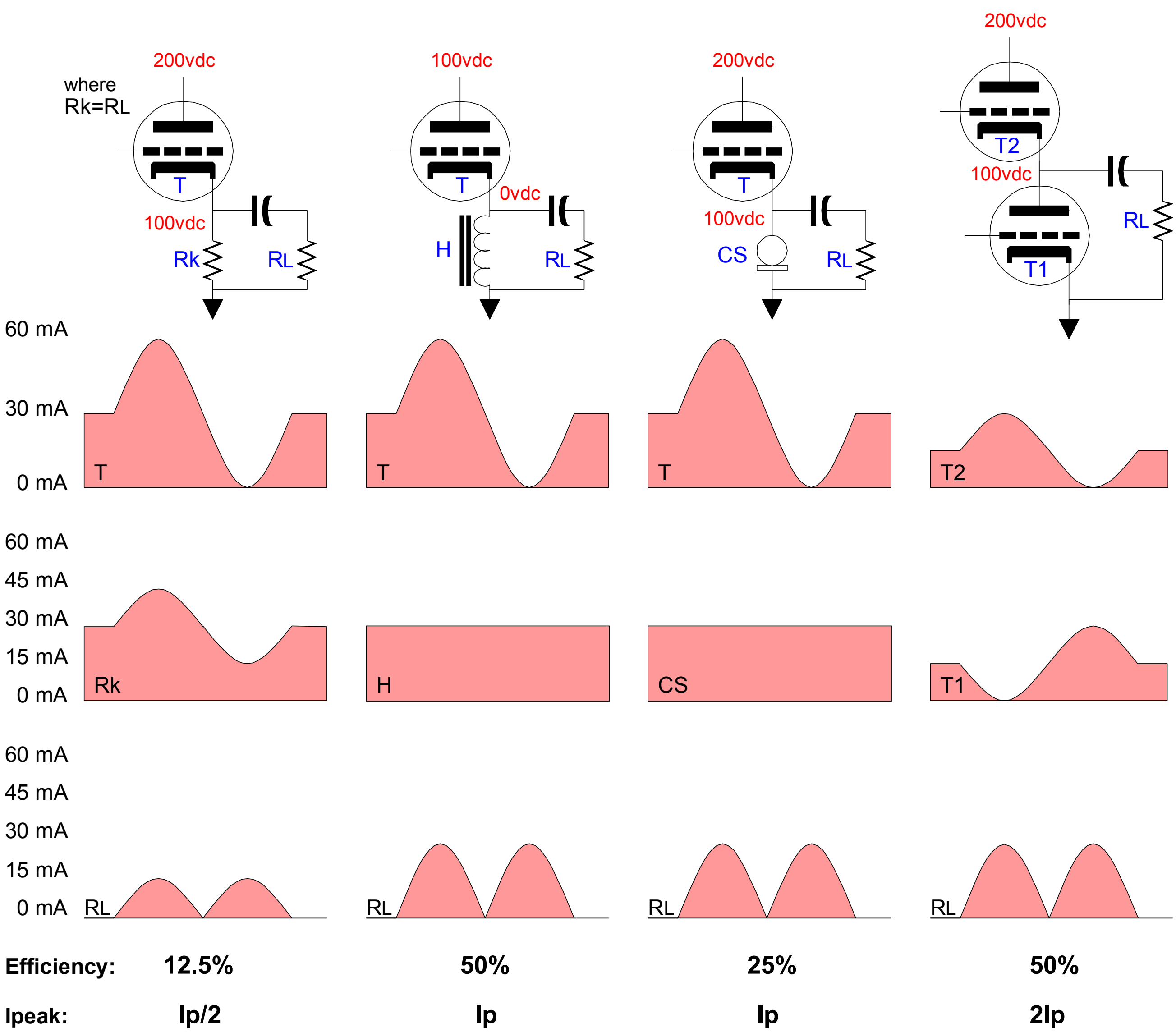
Where the current source loading allowed *all* the idle current to be delivered into the load, the resistor loading prevents the *full* idle current to ever be delivered. This limitation arises from resistor drawing a varying amount of current depending on the voltage across it. When the voltage increases, so to the current through the resistor. Thus when the amplifier's output tries to pull the load up in voltage, it must also pull the load resistor .



How much current is available from the resistor loaded amplifier? Assuming a capacitor coupled output or a DC coupled output with a negative power supply for the loading resistor and the loading resistor equaling the load impedance, the peak negative going output current is one half the idle current. For example, if the idle current is 30 mA, then only 15 mA can be delivered into the load when the tube is cutoff. The math is simple enough: when the tube is cutoff, the load impedance sees the negative power supply voltage or the voltage stored in the coupling capacitor, through the loading resistor; and as these two resistance equal each other, the load impedance only sees half of the available voltage and thus half the idle current. What if a different resistor ratio is used? Greater voltage or current can be delivered into the load impedance, but at lower amplifier efficiency.

Now you can readily see why push-pull, Class AB, B is so popular. Well then, the answer seems easy enough: use either an inductor or current source to load the output stage. Now a few problems arise. First, finding high quality, high inductance, small chokes is not easy. Second, small, high inductance chokes have a correspondingly high DCR, which will displace some of the precious B+ voltage. Third, active current sources do not function all way down to zero volts; instead, their impedance falls when the voltage differential falls to just a few volts in the case of solid-state current sources, and tens of volts in the case of tube current sources.

In other words, while these devices are in general good ideas to implement, we may not gain all the efficiency enhancement promised by these devices. What about output transformers? In theory, this would be the best design path to pursue, as a transformer would provide both a better impedance matching between tube and headphone and a means of protecting the headphone from DC offsets. But in practice, it is extremely difficult to find high quality low wattage output transformers that offer bandwidth down to 20 Hz. Additionally, the simplicity of a single resistor and coupling capacitor are truly compelling.



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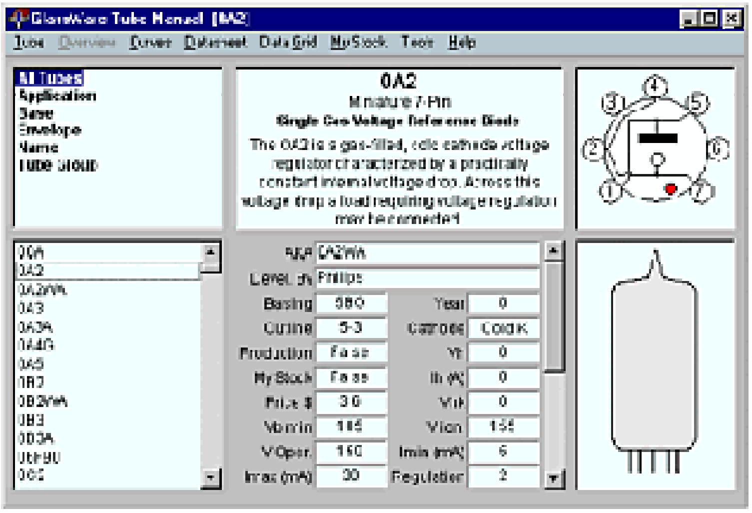

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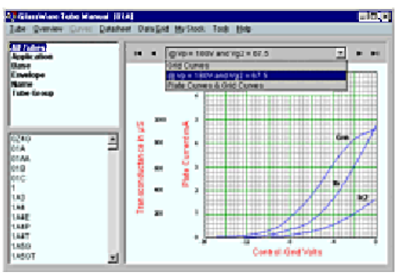
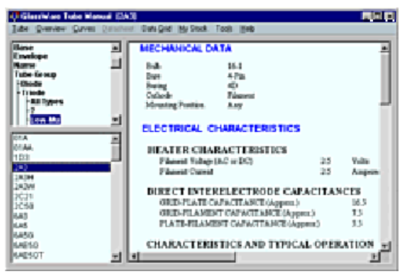


Plate Curves



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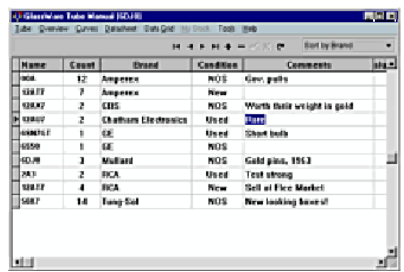
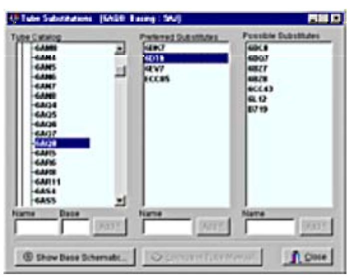
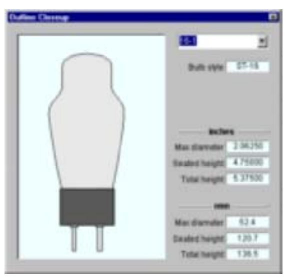


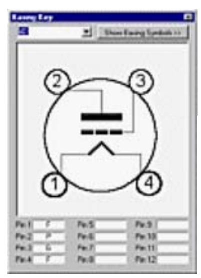
User's own stock DB



Tube Substitutions

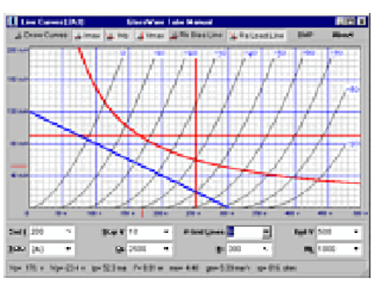


Tube Outlines



Tube Basing

Complex DB Filtering



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Compliant Current Sources

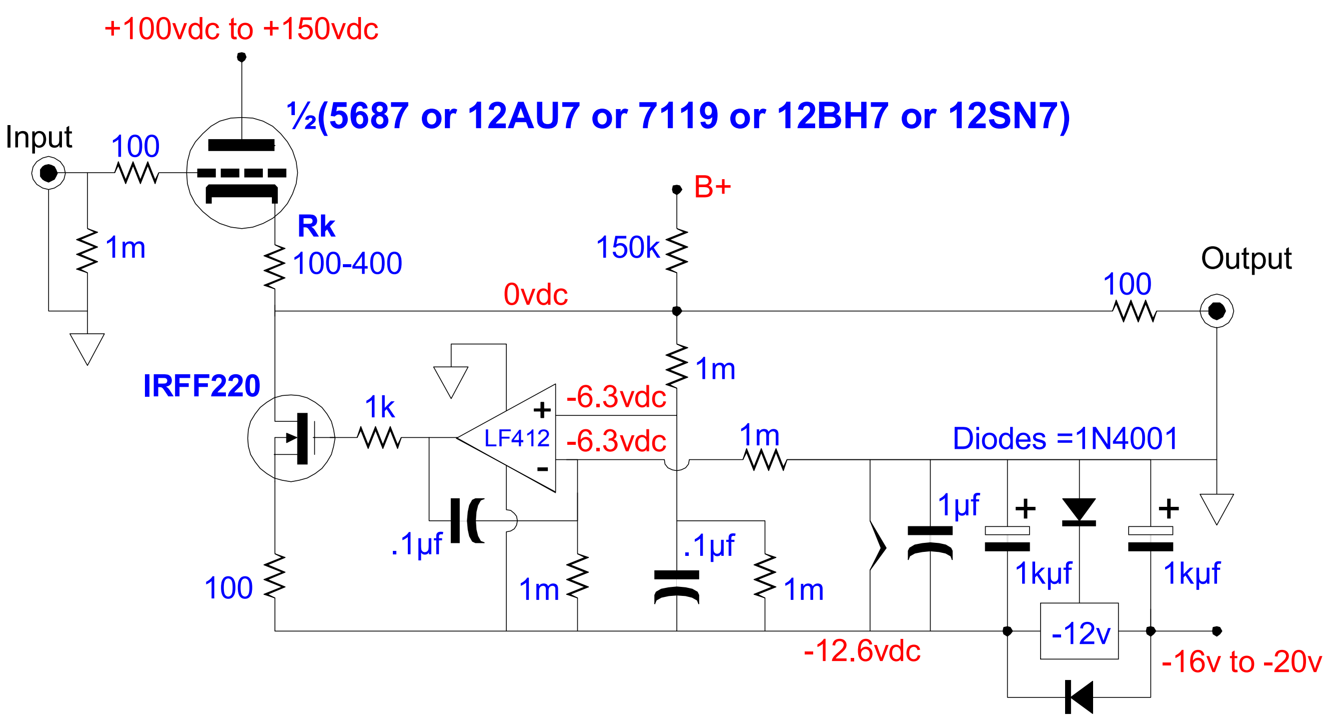
If by adding sufficient circuitry we can eliminate the coupling capacitor, then the added complexity might well be worth the effort. A DC servo loop can be wrapped around the current source, rather than the tube. This creates a compliant current source that tracks the tube's quiescent current and nulls a DC offset at the output. This circuit was covered in a GlassWare Tube circuit of the Month article, ***No Gain, No Pain*** and is quoted here:

This trick consists of a Cathode Follower that is loaded at its output by a compliant current source, that is a current source that does not have a predetermined quiescent current. What is constant about it is that it strives to maintain a DC ground potential input regardless of the current flowing through it.

Is it then really a current source? In AC terms, yes; in DC, no. It offers a very high impedance (roughly, 1 meg) to any AC signal it sees and in this respect it is identical to a typical active current source. In DC terms it works to adjust its quiescent current until its input is zeroed at ground potential (0 volts) over time (roughly, 3 Hz).

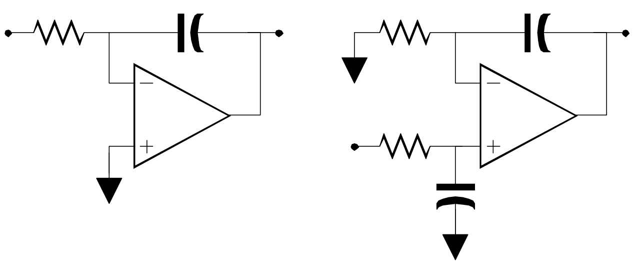
This piece of magic is the result of a DC servo loop that is wrapped around the input of the current source and the output of the Op-Amp. If the input moves toward the positive over a long period of time, that net DC drift is fed into the non-inverting input of the Op-Amp, which causes its output to go positive. This positive voltage will further drive the MOSFET into greater conduction, which will pull the output towards negative. On the other hand, if the output moves toward the negative over a long period of time, that net DC drift is fed into the same non-inverting input of the Op-Amp, which causes its output to go negative. This negative voltage will move the MOSFET into less conduction, which will move the output towards positive.

The subtlety here is that the MOSFET is within the DC feedback loop, but outside the AC feedback loop of the Op-Amp. As the time constant of the RC network made up of the two 1 meg resistors in parallel and the .1 µf capacitor is so long that no music can fall into it, the Op-Amp presents a virtually constant DC voltage to the gate of the MOSFET. This steady voltage sets the amount of current that flows through the MOSFET; if the tube's idle current drifts over



time, the Op-Amp's output will drift with it. While responding to the music signal, the Cathode Follower's output voltage and current will vary, but variation is far too fast to register at the input of the OP Amp and will be ignored. (If the Op-Amp's is extended to include the source of the MOSFET, then the Op-Amp would respond to the change in current through the Cathode Follower. Not a good idea.)

The 150k resistor that connects from the B+ voltage to the output is there to give the compliant current source a current path in the absence of a tube in its socket or at startup when the tube has yet to conduct any current."



Basic integrator and non-inverting integrator

The basis of the compliant current source is a non-inverting integrator, which is nested in an inverting integrator. (If your head is beginning to hurt, jump to the next section.) The MOSFET is configured in a grounded source topology that inverts the output; the tube, a cathode follower topology that doesn't invert the output phase. Thus the overall effect of this circuit is to apply a DC servo loop to the cathode follower output and to match the idle current of the cathode follower with a AC current source.

This circuit eliminates the need for a coupling capacitor. If feat seems trivial, then maybe the math involved should be reviewed. The coupling capacitor's value is set by:

$C = 1/(2\pi FR)$,

where C is in farads and F is the lowest frequency and R is the resistance of the headphone; rewriting the formula for microfarads yields:

$C = 159155/F/\text{Resistor}$.

For example, given a low frequency cutoff of 20

Hz and an impedance of 32 ohms, the coupling capacitor value must equal 250 µF. Two of these capacitors were they high quality film capacitors would fill a large cabinet, leaving no room for the circuitry and batteries! The alternative to using film capacitors is either using electrolytic or a blend of electrolytic and film. Working on the assumption that the best capacitor is no capacitor, this circuit is definitely worth a second look.

A Transformer Coupled Example

Transformers help tubes work into low impedance loads and they also protect the load from the high voltage on the other side of the transformer. Both these tasks seem ideally suited to a tube headphone amplifier. Even 300 ohm headphones are awfully low for most tubes and even a small DC offset at the output could damage the headphone's drive element. A good transformer could leverage the even Grado's 32 ohms up to a manageable 3200 ohms and offer zero DC offset.

The problem is finding a good transformer. Even the best transformer in the world isn't all that good. Aside from bandwidth issues, a transformer is plagued with a large size and heavy weight, leakage inductance, primary and secondary DCR, saturation, eddy currents within its core, proximity hum pickup, physical noise generation, and sometimes untamable high frequency resonances. Add to this list that headphone impedance spread of 32 to 300 ohms makes finding a transformer with useful secondary taps difficult. Let us also add to this list that array of useful output transformers has shrunk since the tube glory days; I have a few old catalogs that list a few ideal transformers (out of hundreds and hundreds that were not suitable) that are no longer in production. The capacitor does not look so bad now does it?

Assuming that a good transformer can be found, the design of the headphone amplifier is really no different from the design of power amplifier, a smaller in scale, but not fundamentally different.

The single-ended amplifier's general of 2rp for a primary impedance is a good starting point. Given that the spread of useful rp's begins at 1k and ends at 4k, we need a transformer whose primary impedance falls between 2k to 8k and centers on 4k. A primary of 4k coupling into a secondary of 300 ohms gives us a winding ratio of 3.65:1, as dictated by the formula:

Ratio = √(primary / secondary).

We need to know this ratio because it is unlikely that we will find a transformer specified for a 300 ohm secondary load. In other words, a transformer that has a primary impedance of 8k and a secondary of 600 ohms has the required winding ratio. The ratio also gives the current magnification and the voltage division from primary to secondary. For example, a 36.5 volt swing and a 1 mA current swing on the primary equals a 10 volt and 3.65 mA swing into the 300 ohm load impedance. In addition, the ratio indirectly gives us the output impedance, as the ratio squared is the impedance ratio of the transformer. Thus, for example, an rp of 2k becomes an output impedance of 150 ohms.

With secondary of 300 ohms how do we drive 32 ohm headphones? If the secondary winding does not have multiple taps, we don't try, in this case, our best bet is to find a transformer with an 11:1 winding ratio and preload the secondary with a 100 ohm resistor. This resistor will give the transformer's limited inductance something to bite on when the load is 300 ohms. But if the secondary has multiple taps, the going gets easier. A center-tap will yield a secondary impedance of 75 ohms; a .707 tap, 150 ohms; third-tap, 33 ohms. In other words, a center-tap increases the winding ratio by 2.

The next question is where to place the transformer. Should it go at the plate or the cathode? Should it be used directly or in a para-feed arrangement? The plate loaded amplifier gives us gain; cathode loading, a much lower output impedance and less distortion, but at the cost of no gain and a high input voltage swing; and a para-feed arrangement, a potentially lower noise output and no primary current.

Furthermore, nickel based transformers have cores that cannot abide unbalanced DC current, as they saturate easily in the presence of unidirectional DC current. But by using a using a coupling capacitor in a para-feed arrangement we ensure that there is no net DC current. In other words, the para-feed arrangement allows for the use of a higher quality output transformer. I am sure that either the Jensen transformer company or SESCOM might have an excellent nickel transformer on the shelf

Plate loading, with either para-feed or directly arranged, might allow for only getting away with only one triode per channel, i.e. one tube envelope, as the output transformer's stepping down of the output voltage would be cancelled by the plate's gain. Feedback could even be wrapped around the amplifier to a small degree. Two such amplifier layouts are shown below.

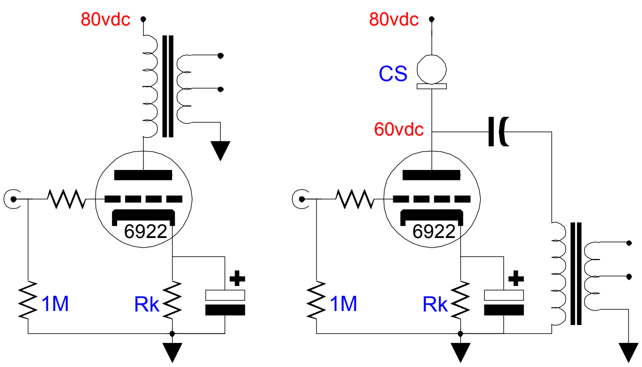
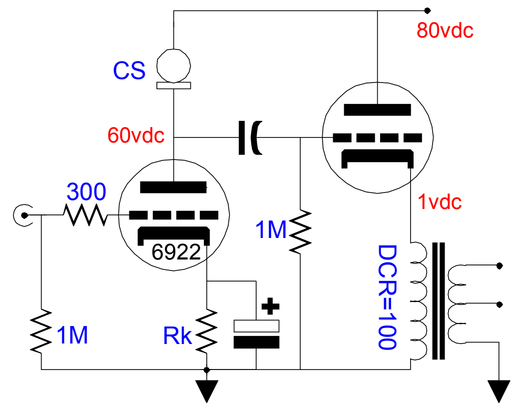


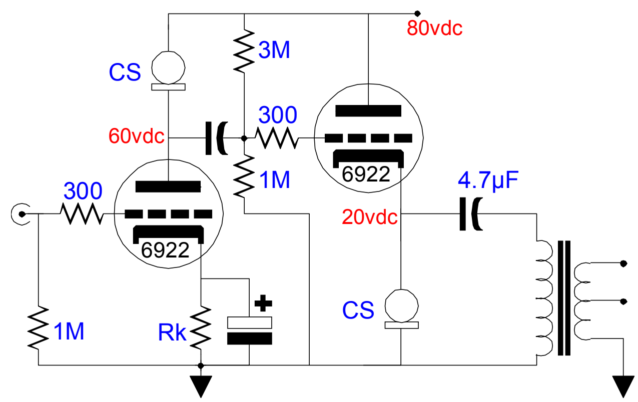
Plate loaded headphone amplifiers

Note that the para-feed arrangement shown above does not use a choke, but instead a solid-state current source. The current source might prove a better choice than a choke, as high quality chokes are also hard to find. Most chokes were designed for use in power supplies and do not work well across the audio band. A simple test of a choke is to place two in series with each other. Then ground one end of the string and attach the other end to a function generator. Finally, observe the waveform fidelity at the midpoint between the two chokes on an oscilloscope.

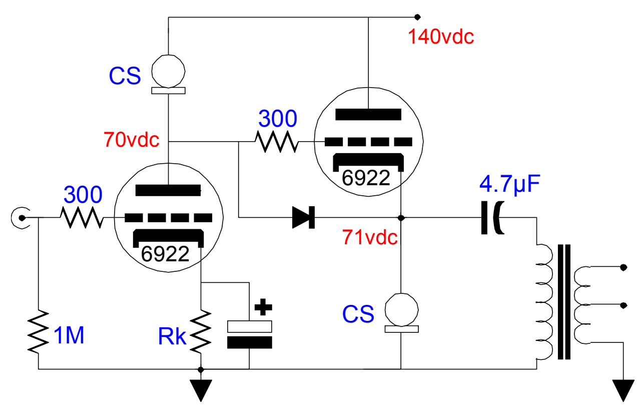
On the other hand, cathode loading, with either para-feed or directly attached, will necessitate at least two stages and thus at least two tube envelopes, and thus half the available battery time. But this penalty might be worth the benefits of a lower output impedance and lower distortion. Two such amplifier layouts are shown below.



Directly cathode loaded headphone amplifier



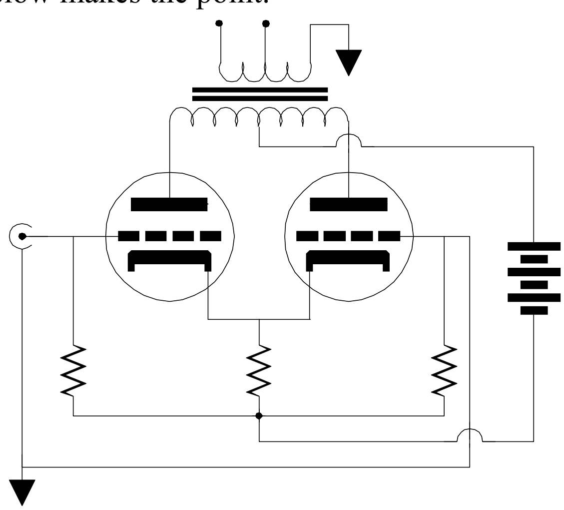
Current source cathode loaded amplifier



Note the 140 volts power supply requirement of the third schematic, which is the cost of eliminating the interstage coupling capacitor. But the increase in available cathode-to-plate voltage must be added to the advantage list.

Push-Pull Transformer Coupled Amplifiers

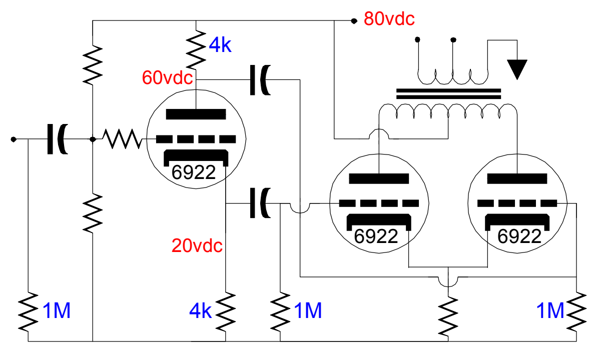
Since the music sources, portable CD players, MP3 player, and pocket FM radios, are all single-ended output devices, a phase splitter will be needed to drive a push-pull output stage, which will greatly increase the complexity and tube count of a design. Or will it? The White cathode follower and the SRPP are push-pull circuits that accept a single-ended, an unbalanced input. And even a traditional push-pull output stage with two output tubes sharing a common cathode resistor and plates terminated into the output transformer's primary, may get away without a tube phase splitter. An input transformer with a center-tapped secondary is a phase splitter. Additionally, a phase splitter can be from as little as a two resistors! The circuit below makes the point.



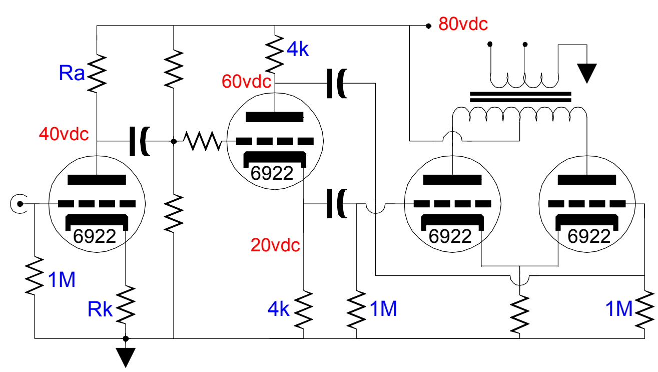
Phase splitter by two resistors

The secret to unraveling this circuit is the realization that the power supply for the output tubes is floating, i.e. it does not find a ground at the source's ground, but rather at the midpoint of the two resistors that span the source's output and the source's ground.

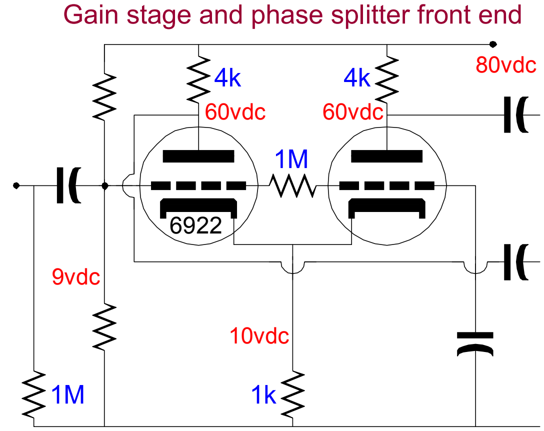
Alternatively, a tube phase splitter could be used so as to eliminating the need for a separate floating power supply per channel, the major liability of the previous circuit. (The minor liability is its halving of the input voltage.) Which phase splitter topology should we use? The answer depends on whether more gain is needed. The split load phase splitter has the best balance, but offers no gain. The long tail phase splitter offers gain, but a poorer balance and requires a second triode. Some possible circuits are shown below.



Split load phase splitter front end



Gain stage and phase splitter front end

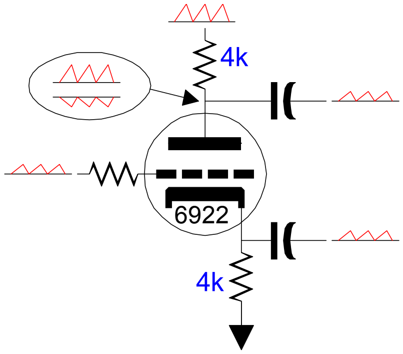


Long tail phase splitter front end

Note the use of the a plate resistor rather than a current source in the first circuit; it was used purposely. It is common knowledge that a push-pull amplifier will reject the amplification of common mode noise, and while this statement needs some fine tuning, it is basically correct. What is not common knowledge is that noise leaving a driver stage or phase splitter may not offer a balanced common mode noise for the push-pull amplifier to reject. For example, if one half of the balanced signal is thick with power supply noise, but other half is wonderfully noise free because of some power supply modification, then the noise will be amplified along with the music. Removing the modification will have the paradoxical effect of lowering the output noise by reintroducing the noise. Noise rejection requires balance in a push-pull amplifier. (Here is a question: How much noise can be rejected when one tube ceases to conduction in a Class AB, B amplifier?)

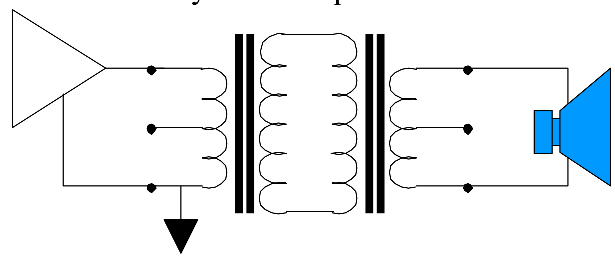
The long tail phase splitter at first glance would seem the easy winner in balanced noise race and the split load phase splitter the clear loser, as it offers a very asymmetric PSRR on its outputs. The reality is that as long as we factor this asymmetry in our calculations, it is not really a concern. As all of this has been covered here before, I will jump to the punch line: if the split load phase splitter's grid receives half of the power supply noise, then the amount of noise on each output phase will be equal in both phase and magnitude. This magic results from the noise leaving the cathode in phase and equal with grid and the noise leaving the plate in anti-phase to the power supply's noise: 1 - ½ = ½.

Power supply noise balancing in a split load phase splitter



OTL Output Stages

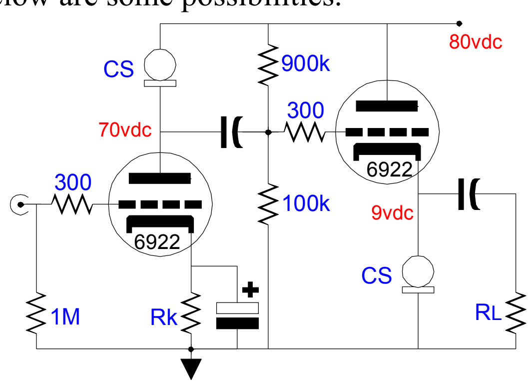
Having scared many readers with the list of transformer faults, let us now examine the alternative, no output transformer. Tube OTL amplifiers have intrigued tube fanciers for decades. The eliminating the output transformer is like releasing the tube from a prison. If you a balking at this metaphor try the following experiment: place two tube output transformers in opposition to each other, i.e. connect the primaries together and attach one secondary to the output of an amplifier and the other secondary to a loudspeaker. If the transformer are perfect the sound from the loudspeaker should not differ from what it sound like when attached directly to the amplifier.

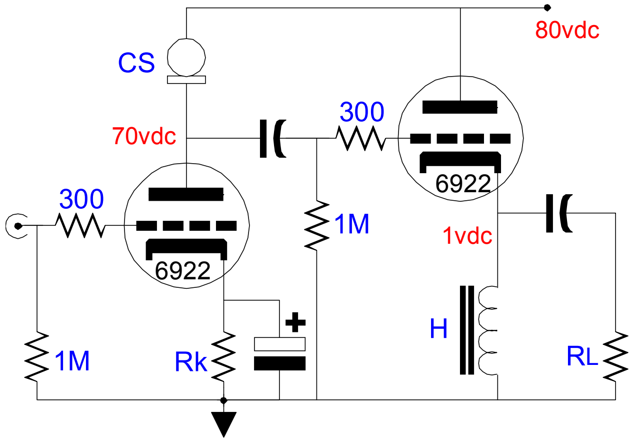


Simple sonic test of output transformers

If you believe that the DCRs of the winding are spoiling the result reverse the transformers and terminate the last primary with a resistor equal to the primary's nominal impedance. Then place this circuit in between your preamp and power amplifier.

On to the *how to make an OTL*. Many mistakenly believe that all OTL amplifier are push-pull. Most certainly are, but need not necessarily be. Single-ended OTL amplifier are possible even for tube headphone amplifiers. Below are some possibilities.





OTL single-ended headphone amplifier

In the second example, the DCR of the choke serves to bias the output tube. Both circuits will just barely drive a 300 ohm Sennheiser headphone certainly not a 32 ohm Grado. More triodes are needed. How many? How much current do wish to deliver into load? Each triode section can yield up to 10 mA with a 6DJ8. How was this figure determined? The best approach is to examine the plate curves of the tube. But for rough estimating, the following formula is useable:

Current = Vp/2rp

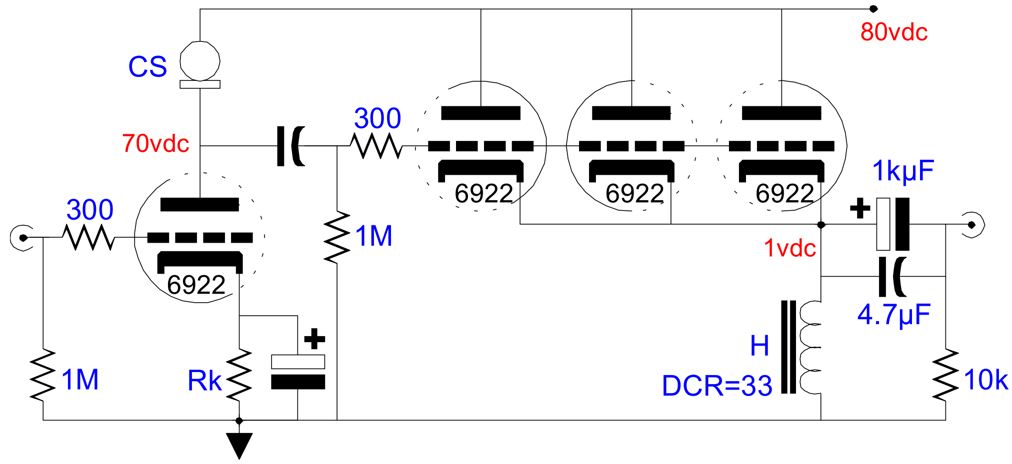
This formula gives us the idle current per output tube as well as the peak output current per tube. Now we take the desired peak output current into the load and divide it by the idle current per output tube. For example, given a B+ of 80 volts, a rp of 3300 ohms, a 9 volt span across a current source, the idle current per triode should be 10.75 mA, as

10.75 = (80 - 9) / (2 x 3300),

which we round down to 10 mA.

Thus a peak of 30 mA into the load requires three triodes. This will bring the tube envelope count up to 4, thus halving the battery playback time. But then no one ever said that Class A, single-ended, OTL was cheap. (Well, no one other than advertising departments).

How was the value of 9 volts picked for the current source voltage displacement? It comes from multiplying the peak output current against the load impedance, 30 ohms. This value is, in practical terms, insufficient. The FET within the current source stops acting as a current source when the voltage drops too far, as it enters its triode region. Even if a more elaborate current source is used, say 3-pin terminal voltage regulator configured as a current source, at some point a dropout voltage will be encountered.

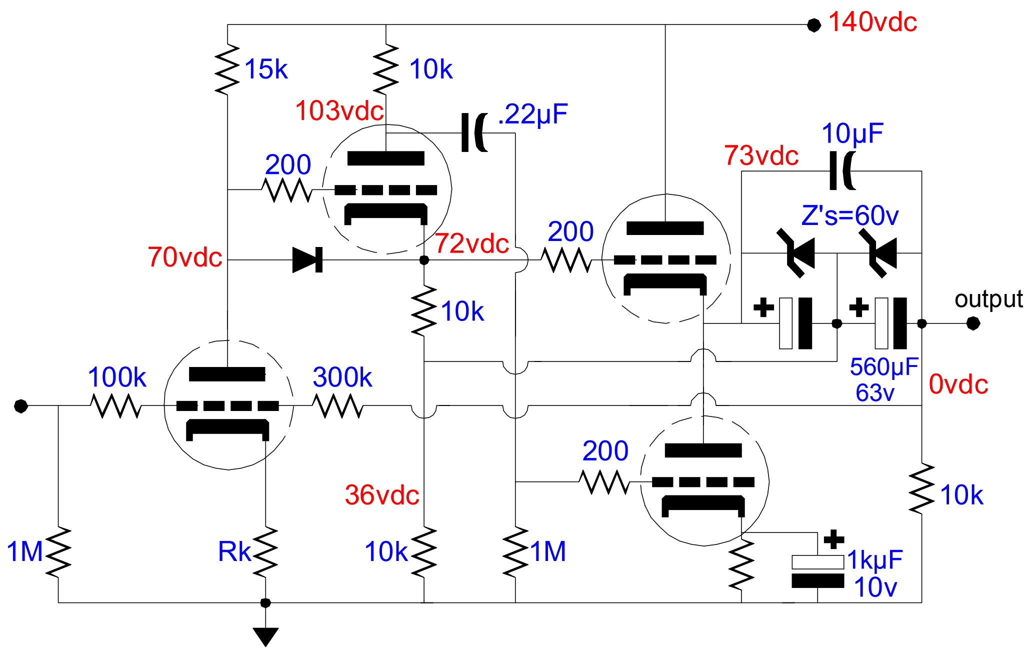


OTL single-ended headphone amplifier using 3 output triodes and a choke load

The choke, on the other hand, theoretically displaces no voltage, but in actual practice the DCR of the choke must be factored into our calculations. If the value is too great to allow the simple biasing arrangement of one capacitor and one resistor at the grid, then a second resistor can be added to pull up the bias voltage from ground potential. Conversely, if the DCR is too low, a resistor, or even a forward bias diode, can be placed in series with the choke to correctly bias the output tubes. In other words, the choke replaces the cathode resistor in a grounded cathode amplifier.

OTL Push-Pull Output Stages

Class A push-pull amplifiers offer the advantage of delivering twice the idle current into the load. The single-ended amplifiers can only deliver the idle current. Understand that the relative efficiency remains the same: 50% tops. The disadvantage of the push-pull totem pole arrangement is that it necessitates twice the B+ voltage, which means that two 72 volts DC-DC converters will be needed. While this seems to constitute a huge liability, but do not forget that tubes thrive on voltage. Doubling the B+ in this example will not increase the output tubes Vp voltage, but it does increase the voltage available to the input and phase splitter tubes.



OTL push-pull headphone amplifier

The idle current of the push-pull output stage sets the peak (Class A) output current, 2Ip. Since we want to avoid positive grid voltages, the idle current must be set carefully. A quick calculation yields the following formula:

Ipeak = B+ / 2(rp + Rl).

This formula not only gives us the peak output current, but by extension, the value of twice the idle current, 2Ip.

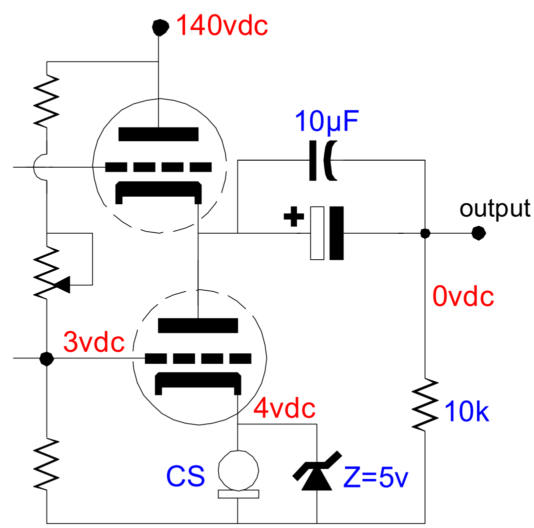
One topological variation worth a second look is the Class A-AB amplifier, which is modeled after the Nelson Pass single-ended amplifier that breaks into Class AB, push-pull functioning after set output is exceed. Yes, it is something like having your cake and eating it as well. Do not forget the most import watt is the first watt. While amplifier may put out peaks of hundreds of watts, most of the listening will be in that first watt. This why crossover distortion irks the ear so much and this is why small wattage single-ended tube amps can triumph over big wattage solid-state amplifiers.

The explanation of the Class A-AB amplifier has been covered in past issues. So let's get down to the details of converting the last schematic to Class A-AB. We want the top triode to be the main single-ended tube. It will be the only output tube experiencing the current variations as it powers the headphone driver. The bottom tube will be the current source that is immune to the input signals. *Up to a certain point that is*. After -4.7 mA has been exceeded, we want the bottom triode to cease acting as a current source and begin acting as an active output device; and once +4.7 mA has been exceeded, we want the top triode to continue conducting current beyond twice the idle current. So what we have is one tube, the bottom one, always conducting some current and the other one only ceasing to conduct after the bottom tube begins to conduct beyond its idle current.

In other words, what we have is a modified Class AB amplifier. If the bottom tube is made to respond to the input in the same way that the top tube must, we would just have a very richly biased Class AB amplifier.

By making the bottom selectively insensitive, we have taken care of two problems with the Class AB amplifier. Class AB amplifiers were devised to correct the gross crossover distortion of the Class B amplifier. By increase the overlap between output devices, the crossover notch where neither device conducted is filled. But this overlap created a new problem: the effective transconductance of the two devices is twice that of a single device. This Gm doubling causes the output impedance to dip over the portion of the overlap. It is as if a crack in the road was repaired by placing a speed bump over it. Where the notch caused one disturbance in the waveform, the Gm doubling causes two, one where the bottom tube ceases to conduct and one where the top tube ceases to conduct. Second, these disturbances often occur in the first few watts where the ear is very sensitive.

The Class A-AB overcomes these two problems by eliminating Gm doubling mechanism and by shifting the transition point between tubes to outside the first few watts. Below is the output stage from the last schematic altered to function as a Class A-AB output stage.



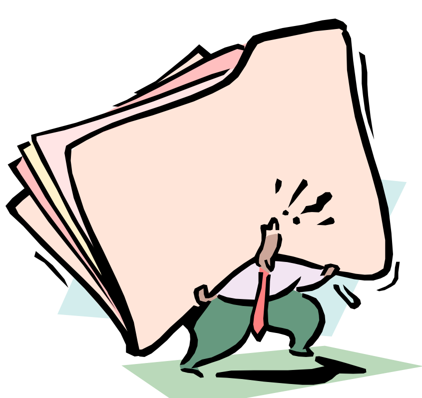
The idle for the output stage is set by the current source. Since 4.7 mA is the limit for the small current regulating diodes, we will choose this value as the idle value. The top triode will function as the amplifier sole output device within ± 4.7 mA, which means that it will deliver the first ±0.15 volts into a 32 ohm load and the first ±1.5 volts into a 300 ohm load. Thereafter, the bottom tube will share in the active driving of the load, as once the input signal exceeds the difference between zener and cathode voltage, the bottom tube becomes active. The potentiometer does not set the idle current, as the current source will adjust the cathode voltage to track the potentiometer's movements. Instead, the potentiometer is used to adjust the transition point between the two tubes. The potentiometer's adjustment should be made with a dummy load and the feedback loop opened. A triangular waveform is perfect for showing discontinuities.

Where do we go from here? The next installment will bring us closer to a final design. Until then, your comments are encouraged and if anyone knows of any readily available high quality output transformer's, please let us know about them.

//JRB

Coming Next Issue

Next time around, we promise we will get around to reviving an old, but good topology for output stages. And expect part 2 of designing a portable headphone amplifier.



E-mail

Subject: printing articles, dropping filament voltages, balanced phono amps

Hi, I got your address out of the current Audio Electronics. I have tried printing out 2 articles, so far. I have a Compaq Presario running IE5 You have stops between each page, so they are printed out individually, each with your header! So, the second page comes out with just one line, listing the title and page 2 or a short remainder, pushed down by the space your header takes up. This wastes twice as much paper! Why don't you fix this? Otherwise, your magazine is quite informative.

A comment on John Atwood's Ultrapath circuit. I tried it with the Fender stand alone reverb CKT - a single ended 6K6 - as I was building a new guitar amp which included it, recently. The output hummed loudly and I traced this to the fact that the capacitor was coupling power supply noise to the cathode of the 6K6 and the tube was amplifying it! I had to add a second choke and cap section to get rid of the residual hum on the B+.

Hot Wall Voltages

I work on guitar amps. Out here on Cape Cod they "improved" the power system a while back. In summer, when it is so hot in Boston that they send the government workers home... and predict brown outs, the line voltage down here is still 123-4 volts! This means that you have 7V on you filaments - perpetually (5.7V on rectifiers) - in your 115-117V amplifier. What to do? You mention in-rush current limiters and there are not many choices. The only applicable ones are CL-10 (CL-11), CL-20 (CL-22) and - I believe - CL-100 (Keystone parts - they have re-numbered them!) These are the three lowest resistance values @ 6, 8 & 16 amp ratings. In practice, they all work about the same. A single one in a typical BF/SF Fender Pro, Twin, etc. with non CT filament winding will bring the voltage down to about 6.3 (or 5) volts. Check it out!

FET Preamps

Allen Wright goes into this in great detail in his Preamp Cookbook! Get the transistors - at reasonable prices - from MCM, 2SK170, 2SK369, single or - I believe - 2SK398? dual version in the BL? or V (medium or high IdSS versions) - MCM does not differentiate, so you can ask them to check, or take your chances. The 2SK147 is no longer with us but these use the same die!

John
(USA)

The whole issue of printing would disappear with the creation of a PDF file for the Tube CAD Journal. Thanks to readers Johan, Ken, and Yury the latest PDF renditions look much better and print beautifully. One problem remains: the files are too large because they hold two identical versions of the Tube CAD Journal issue! Every variable has been tried and it still comes out with a redundant internal file. Once this bug is stamped out, I will post a PDF version of this journal.

As for printing right now, set your browser's page setup options to .25 inch margins and clear the header and footer entries.

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."

As for the hot line voltages you are experiencing, where I live on the California coast, the wall voltage is 122 VAC. But I have a friend who live 70 miles north in San Francisco and his wall voltage is only 108 VAC. He lives in old apartment building that loses 2 volts per floor. Consequently, his heaters are being under heated. What to do?

The answer might be to place the secondary of a 8 volt transformer in series with the primary of your amplifier's power transformer. Depending on the phase relationship between these two windings, the amplifier's transformer will see either plus or minus 8 volts on top of the wall voltage. Because this second transformer need only supply the same amount of current that the power transformer draws it cannot be that physically large.

As for FETs for hybrid preamps, thanks for tips. I have a nice stock of matched 2SK147s and 2SK146s, I haven't had to shop for any for quite sometime. A few words on their use. They are amazingly quiet, which I dearly appreciate. Yet I remember once listening to a $3,500 FET based preamp from one of America's premier solid-state high-end manufacturers that was wonderfully quiet. But after 20 minutes of listening, I felt that something was missing; it was as if it lost not only the noise, but some of the music as well. Four voices became two; room echoes vanished. Of course, some recordings benefit from this subtractive function, but most don't. In other words, more experimentation is required.

Here is another example: I recently made a test of several types of resistors, metal film, bulk foil, carbon film, carbon composition, non-inductive metal film. The test was easy, as only one plate resistor needed to be replaced. The surprise was just how good the carbon composition sounded. Yet, I still remember when I had replaced every carbon resistor in a solid-state preamp with a metal film resistor. The metal film beat the carbon handily. If one carbon resistor sounded much better than one metal film resistor, how can 50 metal resistors sound better than 50 carbon film resistors? Is it possible that the sonically detrimental effects of a metal film are not additive, but those of the carbon resistor are?

The subject of testing components is deserving of an article or two in this journal. We will see what can be put together.

Subject: Circlotron

John I think you need to offer us one more article on the circlotron amp, this time addressing offset adjustment. Like the Atma-sphere boys I plan to use one stage of gain, but cascoded with MOSFET to eliminate the need for a ridiculously high driver stage B+ to obtain the necessary current draw through the triodes and also solving the heater to cathode voltage concern.

Also a pot tying the cathodes together with it's wiper arm connected to a resistor to ground in the first stage, followed by a cathode follower driving twelve 6AS7G's. Global cross coupled feedback will be introduced into the fully differential drive stage. Thanks to you I will be making use of the abundant and cheap supply of 12SN7's or 8SN7's. I find the circlotron to be absolutely simply and straight forward. I implore you to compile all your work into a book, we will buy it in honor of the magnificent tutor you are. You are not of the average tube specie, your articles are modern classics, I'll be on your ass until I see the book.

Rowan

First of al thanks for the compliments. I don't think this circuit is anywhere near being exhausted. Now that I own a pair of Atmo-Sphere MA-1s, definitely expect some more articles.

MOSFET cascoding of a triode does allow for big voltage swings. But do not forget that like all cascode circuits, the cascoded differential amplifier has virtually no PSRR. So either a supremely well filtered or regulated power supply or some of the noise reduction tricks this journal expounds will be needed.

Feedback can be placed at the cathodes of the differential pair or at the top of the plate resistors by cross coupling, which may help preserve the gain of the driver stage.

As for the book, I am asked monthly to come out with a book and I should consider it.

Subject: Ideas for articles

I enjoy you magazine very much, it's just a pity that it is a bit irregular at present, though we all have problems.......

I have an idea for an article which may or may not appeal to you (it doesn't to me, but seems necessary) is one of tube (valve) substitution, particularly in push pull output stages.

What I want to be able to do is replace the KT66's which are becoming far too expensive for me in my Leak TL25+'s, with another valve which has nearly the same characteristics, but need re-biasing to work properly. Perhaps also, I may need to alter the voltage to the screens, but cannot alter the taps on the transformer, for example. So, in effect I need to be able to work backwards in designing an output stage, having certain givens, for example a-a impedance, supply voltage etc. screen taps at 43% etc.

In view of the increasing rarity of some valves, and the almost plentiful supply of similar valves, it seems that an article like this is becoming more and more necessary to keep old amps alive. Maybe the performance won't be as good as original, but that's better than none in my case.

Keep up the good work! (as we say here in England)

Julian

The issue of tube replacement has always been a headache. Amplifiers designed around a certain tube that is no longer made or made well are particularly problematic. The supremely fine EL34s made by Telefunken could handle huge plate voltage that no current EL34 can match. The same holds true of the 5AR4 rectifiers being made today.

What to do? I would give Eric Barbour's kind grunt work on this topic at the Svetlana web site a look. In your particular case I would hunt down one of the better 6L6 type tubes being made today by Sovtek or Svetlana.

Subject: Possible topic for next issue

Firstly I am glad to tell you your Journal being for me the only interesting webzine regarding tubes! My compliments!

Perhaps I have an interesting topic for one of the next issues:

I have experimented with several topologies for hybrid class A power amps to combine the superior voltage gain characteristics of tubes with the current capabilities of solid state devices. Other goals were to eliminate output capacitors, preferably even using no coupling capacitors at all nor using interstage transformers. I really dislike the sound of DC servo circuits sometimes seen.

Today I am rather satisfied with this topology: an ECC83 as long tailed pair receiving the input and the voltage feedback signal DC coupled to a SRPP built around an ECC88. The SRPP is 'grounded' through a 100V zener diode string, carrying 10 ma. The SRPP output I have coupled through a zener diode string into the gates of 2 MOSFETs (2SK1530) in parallel, loaded by a constant current source of 2 identical MOSFETs. This zener diode string conducts 1 mA DC created by a resistor from MOSFET gate to output.

These amplifiers deliver 20 watts in 7 ohm. The sound quality combines detail, warmth, sound staging with firm and precise bass. Especially the 'attack' or liveliness is remarkable. High-end friends are always very impressed.

However, being always looking for improvement, I have following questions for you.

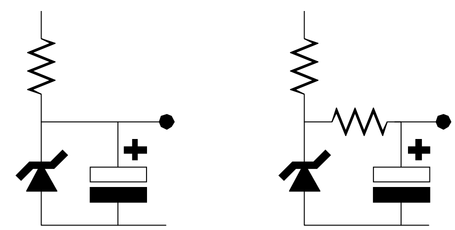
1. what is your opinion on using zener diodes to carry ac (in stead of capacitors or interstage transformers)

2. is there a better substitute for MOSFETS as follower, e.g. a Darlington, Quad triplet or compound transistors? I believe in current gain transistors are essentially more linear than MOSFETs.

3. do you know any other hybrid topology?

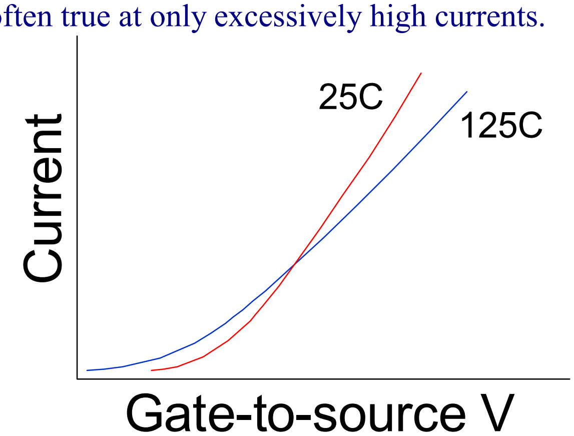
Thank you very much in advance for your time.
best regards.
Harry.

In spite of the plentiful appearance of zener diodes in this journal's schematics, I fear the zener's sometime erratic break voltage and noise. I have found that bypassing a zener seldom eliminates all the noise. Consequently, when a voltage reference is needed, the best plan is to decouple the zener's output with an RC network.



One trick seldom used is just to use a two resistor voltage divider. Yes, you will lose signal voltage, but often we have more signal voltage than we need. But nothing is going to beat the purity of the signal leaving the resistor divider.

MOSFETs are not all that their PR and rumors make them out to be. The high impedance, voltage driven aspect of their grid is welcome, but not the heavy capacitance. The negative conduction with increasing temperature relationship that prevent thermal runaway is often true at only excessively high currents.



Notice that at low currents the positive relationship between temperature and current

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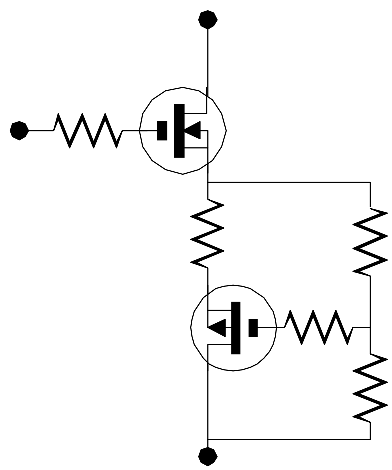
Let's add the lack of true complementary P and N channel devices. Still, are transistors any better? Once again, better for what? If a solid-state uses global feedback, the transistor wins easily. Why? Because it has much greater transconductance, which means more gain, which means more feedback. On the other hand, if the amplifier is feedback free, the MOSFET probably wins, as its static transfer function is straighter. Still only a little emitter degeneration across a small valued resistor performs wonders in straightening out the transistor.

I wish some company would look into bringing out the Gridister or the Lateral Punch Through Transistor. Or maybe we can make a compound device out of existing devices. One such circuit is shown below.



Is it a bird, a plane, a MOSFET, or a triode

The circuit shown above is not efficient, but it may sound great. By selecting the right resistor values, we select the rp and Gm of the circuit Hybrid power amplifiers is a topic that is ripe for an article or two in this journal. Single-ended and push-pull hybrid amplifiers might be the best compromise when a budget is tight. Who knows? It might also be the best compromise period. Let's see what the next issue brings.

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?

Editor
USA

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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