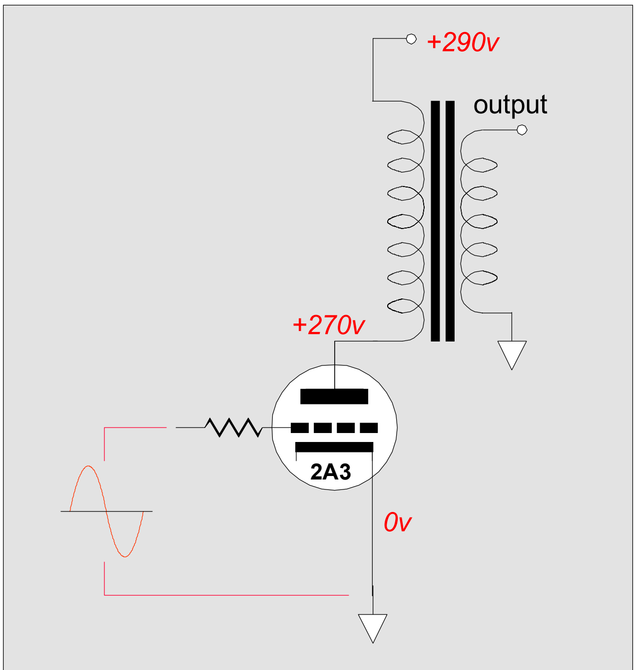
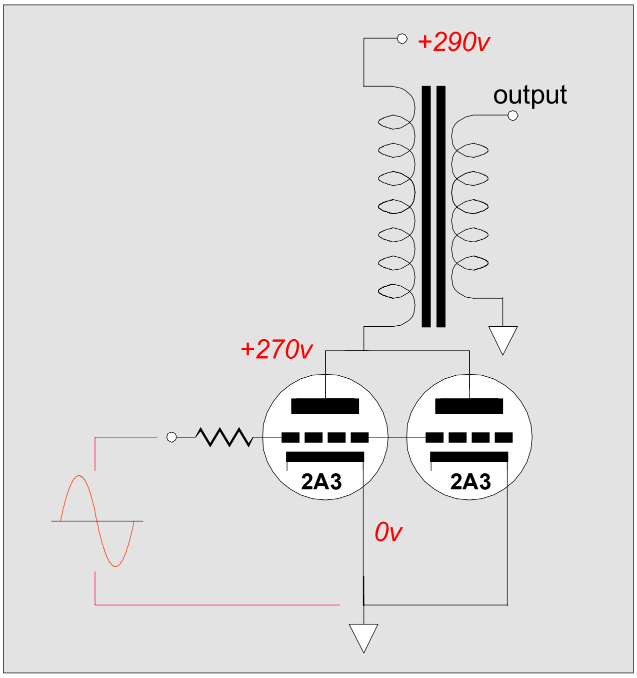
The Accordion Amplifier

A new single-ended topology

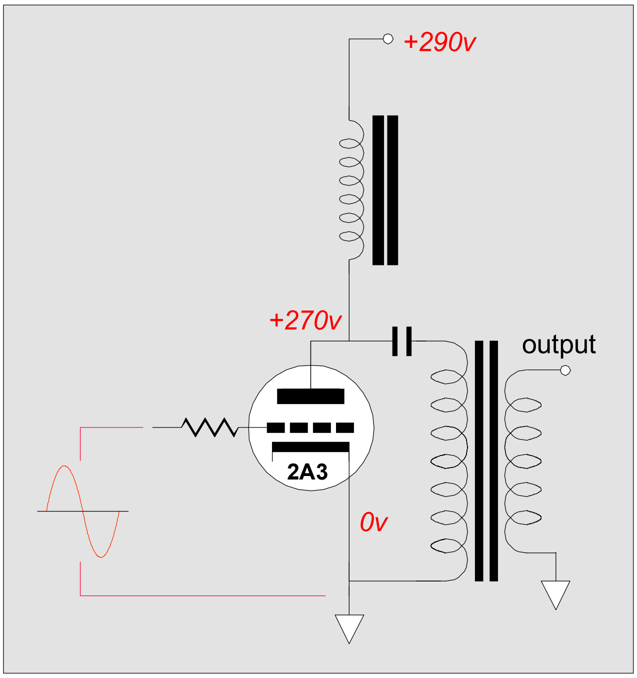
It's time to stir things up a bit: how about a single-ended amplifier that doesn't look single-ended. Single-ended amplifiers have come in basically three flavors: conventional, parallel, and para-feed. The conventional arrangement is shown below. Consisting of just a few parts, this amplifier is conceptually the easiest to understand. (Of course, "easiest" is relative; many do not understand how, when in use, the plate can swing to a voltage more positive than the B+ voltage.) The para-feed arrangement places the output transformer between the plate and ground and uses a choke to mimic a constant current source. (In fact, a current source can replace the choke at the cost of needing a twofold increase in B+ voltage.) This variation provides a better PSRR figure and allows the use of a non-airgapped output transformer, which means that a nickel core material can be used, furthering the transformer's performance. The parallel arrangement is the conventional arrangement but with multiple output tubes.



2A3-based conventional single-ended amplifier



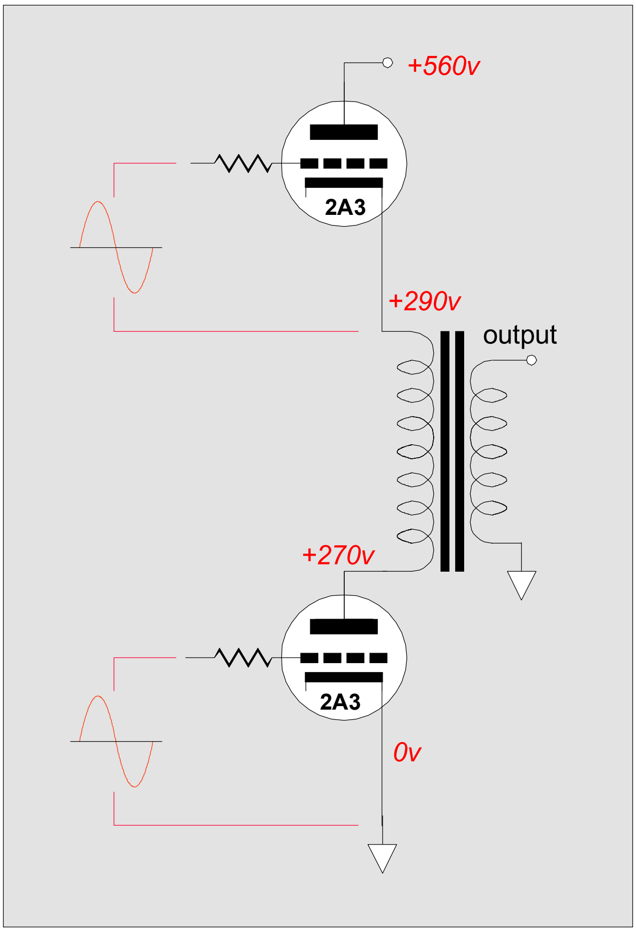
2A3-based parallel single-ended amplifier



2A3-based para-feed single-ended amplifier

The new accordion amplifier also uses multiple output tubes and should be called "the series single-ended amplifier," but why start being sober after almost a hundred years of nomenclatorial whimsy. Besides, the accordion's expanding and contracting nicely symbolizes this amplifier operating principle.

Below, we see the accordion amplifier's topology, two output tubes, one atop the other, with an output transformer wedged in between. Yes, it does look push-pull in nature; yet, it works strictly in a single-ended fashion. And yes, it does look hopelessly asymmetrical, with what looks like a cathode follower on the top and a common-cathode amplifier below; yet, perfect symmetrical operation can be observed.



2A3-based accordion single-ended amplifier

Before going into the details, let's look into what can be seen in the above schematic. We see that both tubes are presented with an in-phase input signal, compelling an in-phase current conduction, thus eliminating the need for a phase splitter because of the single-ended functioning. Compare this to a push-pull output stage, defined by the output devices working in anti-phase conduction to each other, i.e. as one conducts more, the other conducts less.

In the accordion amplifier, like the parallel single-ended amplifier, both tubes conduct equally and in unison. When both output tubes increase in conduction, the top triode pulls its cathode connection to the primary up towards the B+ voltage and the bottom triode pulls its plate connection to the primary down towards ground. When both tubes decrease their conduction, the top triode allows its cathode to swing down towards ground and the bottom triode allows its plate to swing up towards the B+ voltage. (Yes, they do meet and ultimately pass each other, the top triode's cathode being at a lower voltage than the bottom triode's plate voltage.)

If the phase of the input signal to one of the parallel or accordion amplifier's output tubes is reversed, the amplifier ceases to amplify, as the output transformer does not see a change in current flow; and it is the change in current flow through the primary that drives the secondary. Once again but in greater detail, since the output transformer relays the delta (the difference) in current conduction through its primary, if the primary sees a constant DC current flow, then the secondary will remain idle. In these examples, the net conduction can never break away from the idle amount, as the output tubes conduct in anti-phase. Wait a minute: one output tube sees an increasing grid voltage, while the other sees a decreasing grid voltage, so how can the current not change?

Let's consider the parallel amplifier first. If the phase of the input signal to one of the output tubes is reversed, then one tube will increase its current conduction while the other's decreases. The sum will equal the idle current, as one tube's increase in conduction is matched by the other tube's decrease in conduction. For example, +10 mA added to -10 mA equals 0 mA. Of course, real tubes are not perfectly linear, so there will be some small change in net current flow equal to the imperfection of tubes and their relative match to each other. (In fact, this might be an excellent test of the degree of matching and non-linearity.)

Returning to the accordion amplifier, the primary is in series with both output tubes and has no other connection to the power supply other than through the output tubes. Thus, if the chain (the electrical circuit) is broken at any point, the current ceases to flow. For example, imagine removing one output tube while the amplifier is in use. Furthermore, since there is but one current path, all three elements (both output tubes and the output transformer primary) must see an equal current flow. This makes sense, but why can't this net current vary with opposing signals applied to the output tubes?

If the bottom tube in the accordion amplifier sees a +20 volt pulse at it grid and the top tube sees a -20 volt pulse at its grid, the bottom tube will pull down as it tries to conduct more and the top tube will let go as it tries to conduct less. If we look at only the voltage swing that the bottom triode's plate undergoes, we might be fooled into believing that the amplifier is still delivering power into the load; it isn't. The transformer's primary still sees the same voltage across it as it did at idle.

What is happing is that as the bottom tube's cathode-to-plate voltage drops, its cathode-to-grid voltage is increasing. And the inverse situation is taking place at the top triode; as its cathode-to-plate voltage increases, its cathode-to-grid is decreasing by a ratio equal to the triode's mu, a constant current flow. It's almost as if the top triode had been replaced by an active constant current source. Why doesn't the same principle apply to the conventional single-ended amplifier? It does, but to a much smaller degree. The plate's movement subtracts from the triode's gm, which means that the triode undergoes a smaller current swing than it would if the plate had attached to the B+.

Notice the inverse relationship between the parallel and the accordion: the parallel amplifier sees its output tubes undergoing large anti-phase current swings (yet constant cathode-to-plate voltages), but the accordion amplifier sees large anti-phase cathode-to-plate voltages swings (yet at a constant current draw).

If we return the accordion amplifier's inputs to their correct phasing, we see how the amplifier can only work when its single current path undergoes a variation in current draw, which can only happen when both output tubes conduct in unison. Furthermore, because the accordion amplifier works in a strictly single-ended mode, this amplifier will not cancel even-order harmonics or common noise signals. Nor can this amplifier be used in any other class than true, pure Class-A. Nor will it allow the direct use of a non-airgapped output transformer, as the primary still sees an unidirectional current conduction. So if the accordion amplifier still functions entirely as a single-ended amplifier, why bother? The answer is the same as the one for why we bother with the parallel single-ended amplifier: flexibility.

Flexibility

Let's say you need twice the miserly 8 watts that a single 300B yields: paralleling two 300Bs will give you that twofold increase. Or let's say you have inherited a single-ended output transformer with a primary impedance of 800 ohms: using three 2A3s in parallel will match this impedance nicely. Both of these examples illustrate how we can achieve either the wattage or the impedance match we desire by paralleling output tubes. But let us now imagine different scenarios. Let's say you have a regulated power supply that puts out 560 VDC and you have your heart set on using 2A3s. What can you do? Paralleling will not limit the plate voltage, as each 2A3 will still see the full 500 volts. But placing the two output tubes in series will halve the cathode-to-plate voltage that each tube will see, as the two tubes in series define a voltage divider. Or let's say you that you inherited a single-ended output transformer with a primary impedance of 5000 ohms, far too high for a single 2A3. But with the two tubes arranged in the accordion topology, the transformer's primary impedance is effectively halved, or rather, the 2A3's rp is effectively doubled, making an excellent match.

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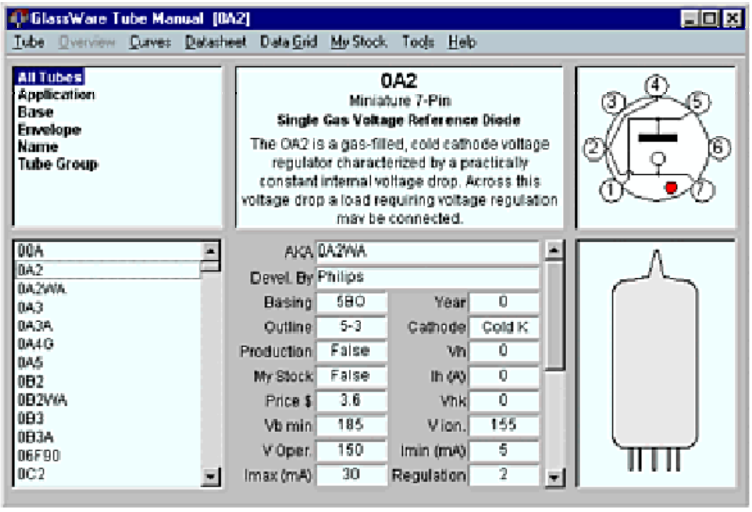

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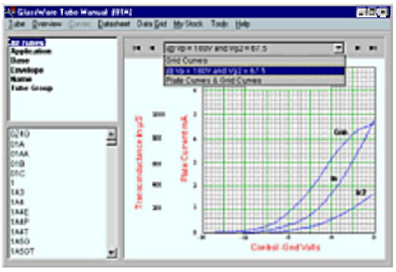
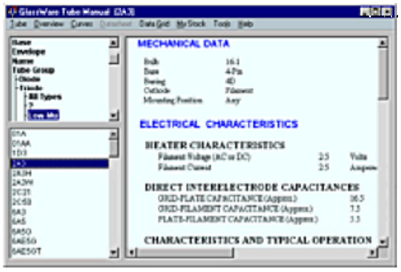
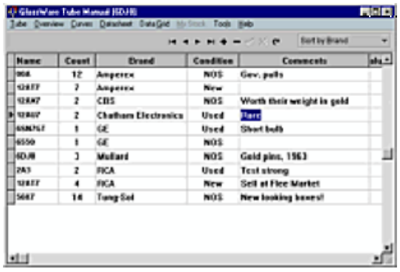


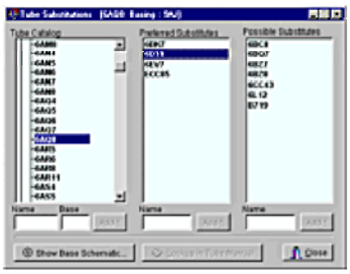
Plate Curves



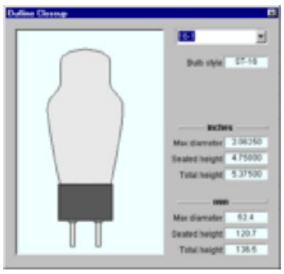
Datasheets



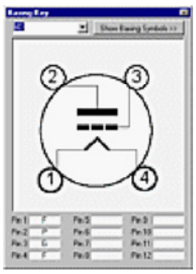
User's own stock DB



Tube Substitutions

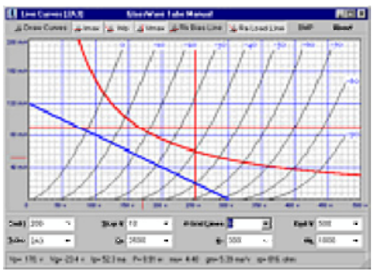


Tube Outlines



Tube Basing

Complex DB Filtering



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The increased flexibility afforded by the accordion amplifier is similar to the increased flexibility afforded by the isobarik (constant pressure) loudspeaker enclosure, wherein two bass drivers are used, one in back of the other, effectively halving the V_{as}, while maintaining the same radiating surface (F_s and Q). Prior to this loudspeaker design, the only other arrangement was placing two loudspeaker drivers side by side on the front panel, doubling the radiating surface, but also doubling the V_{as}.

Z_o, g_m, r_p, and mu

The details should never be forgotten. Isn't God to be found in the details? What is the output impedance of an accordion amplifier? And while we are at it, what is the output impedance of a parallel single-ended amplifier?

Surprisingly, in all three topologies--the conventional, the parallel, and the accordion--the output impedance remains constant, providing that all use the same output tube and are optimally matched to the load impedance. How can this be? Doesn't using twice the number of output tubes in a parallel single-ended amplifier halve the output impedance? It might, if we retain the same output transformer winding ratio, which would reflect the halved rp of the output stage to the secondary. But this seldom is the chosen path, as retaining the same output transformer means that we do not double the output power. By doubling output tubes, we effectively double the output transformer's primary impedance, which although it serves to lower the distortion, also moves us away from the optimal power transfer into the loudspeaker. In order to return to optimal use, we must also halve the transformer's primary impedance.

If we had been loading a single 2A3 with 2500 ohms, the maximum plate voltage swing might be 100 volts. But using two 2A3s in parallel might only increase the maximum plate voltage swing to, let's say, 110 volts, a value insufficient to double the power output. However, using an output transformer with a primary impedance of 1250 ohms will retain the 100-volt plate voltage swing, but at twice the current swing, which then yields the desired power doubling, but retaining the same output impedance. The lower impedance transformer has a concomitantly lower winding ratio. This ratio squared gives us the transformer's impedance ratio. In other words, we have halved both the rp and the impedance ratio by using two output tubes in parallel with an output transformer with half the primary impedance; the result is unity. For example, the 2A3's rp equals 800 ohms, which when divided by the 2500 ohms output transformer's impedance ratio of 312.5, equals 2.5 ohms as the output impedance. Using two 2A3s in parallel with a 1250-ohm output transformer yields an effective rp of 400 ohms, which when divided by this transformer's impedance ratio of 156, equals the same 2.5 ohms output impedance. So what do we gain by paralleling two output tubes? We can either double the power output or halve the output impedance, but not both.

Men do not like to give up power; no man wishes he were shorter. So giving up potential watts is painful, but maybe it’s the better choice. Maybe a 2A3-based single-ended amplifier (sporting three output tubes and delivering just 3.5 watts, but with a one-ohm output impedance and the ability to drive ugly reactive loads) would sound much better than a 10-watt version.

Comparison of single-ended topologies

	r_p	mu	g_m	B+	I_q	Z_o	W_o
Conventional	1	1	1	1	1	1	1
Parallel	0.5	1	2	1	2	1	2
Accordion	2	2	1	2	1	1	2

The accordion amplifier also yields unity when working into an optimal load. The series connection does double the effective rp of the output tubes, but since the output transformer's impedance is also doubled, the output impedance remains the same. Wait a minute: doesn't the top tube function as a cathode follower, which would greatly reduce the output impedance? The answer is that even if the top triode did function as a cathode follower, which it need not, the bottom triode's rp would still spoil the chance of a lower output impedance.

Depending how the drive circuit is arranged, we can configure both output tubes as either cathode followers or grounded-cathode amplifiers. But as drawn, the accordion amplifier uses both triodes as grounded-cathode amplifiers, as the top triode's input is not referenced to ground, but to its cathode. Thus a voltage pulse applied to the secondary would reflect back to the primary, forcing the bottom triode's plate down and the top triode's cathode up. And since the top tube's input signal is referenced to its cathode, its grid will see the same positive pulse. In other words, the voltage pulse across the primary sees only the two output tubes' own internal resistance as a load. Thus, as configured, the rp is doubled.

Interestingly enough, the mu is also effectively doubled while the gm remains the same, as the same change in current results that would have resulted with only one output tube. Why does the mu increase? The answer lies in the series arrangement. The amplification factor of the two tubes in series must be added together, as the load impedance sees twice the gain that it would with only one output tube. Mathematically this makes sense, as the constant gm against the doubled rp equals twice the mu. The formula to memorize is;

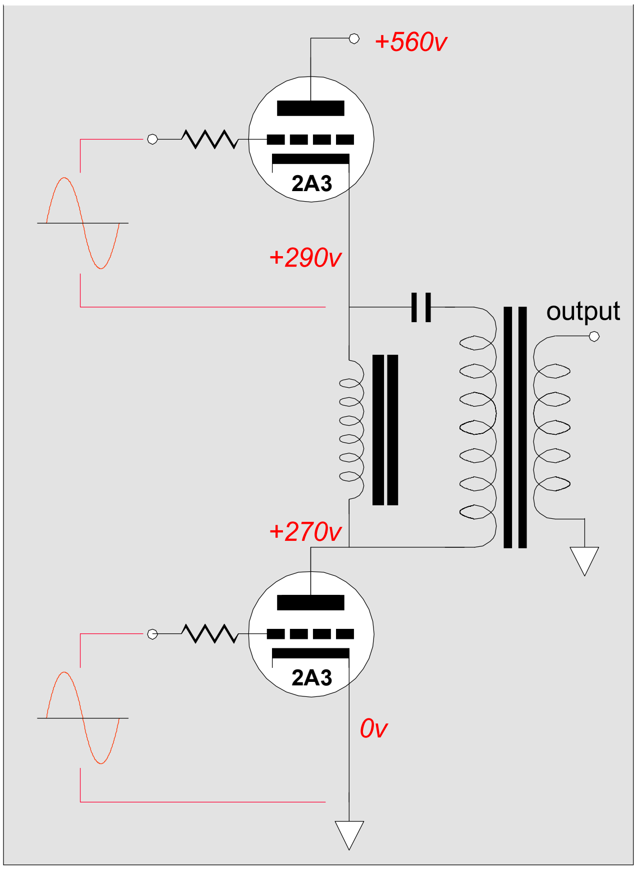
$$mu = r_p \cdot g_m$$

Compare this to the parallel configuration, wherein the gm is doubled, but the rp is halved, which equals the same mu, as

$$mu = r_p/2 \cdot 2g_m$$

A Para-Feed Accordion Amplifier

The para-feed amplifier is not a fundamental topology; it is a technique that can be applied to both single-ended and push-pull amplifiers. For example, in the circuit below we see a para-feed version of the accordion amplifier. The DC current path between output tubes is maintained by the choke and the coupling capacitor prevents DC current from flowing through the output transformer, allowing the use of nickel-core output transformers.

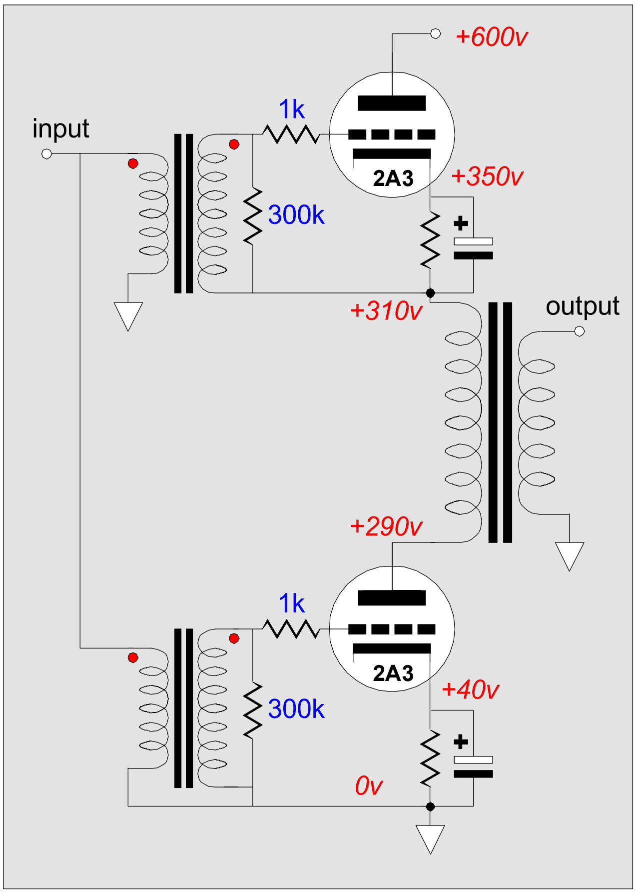


Para-feed accordion amplifier

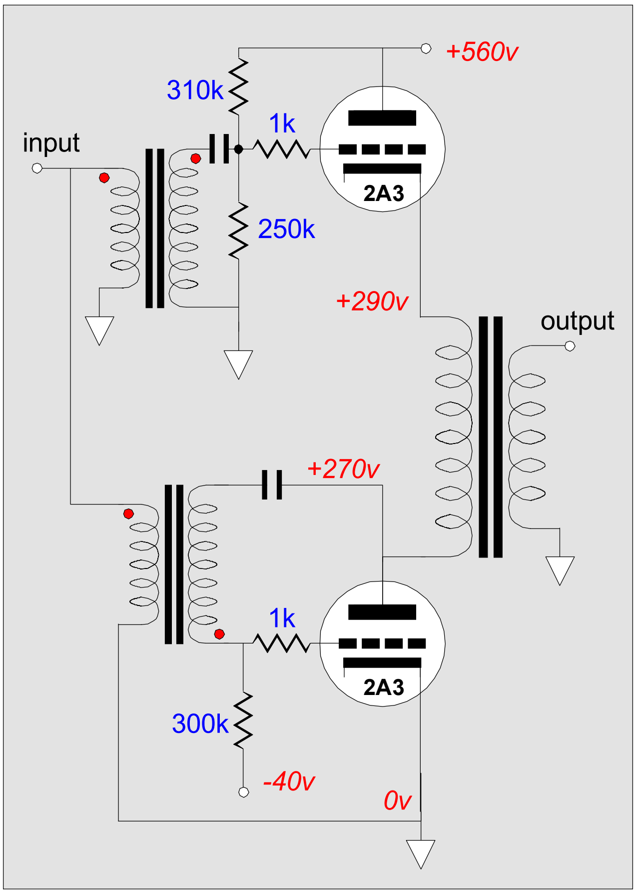
The main advantage of this variation lies only in its ability to use a higher performance output transformer. One para-feed advantage, a better PSRR figure, is absent from this amplifier. The choke does not shield the output transformer from the power supply noise as it would in the more conventional para-feed amplifier. But by using a few noise canceling techniques or brute force techniques, we can substantially reduce the output noise.

Driving the Accordion Amplifier

First of all, we do not need a phase splitter, which is a relief. Still, we have some work ahead of us. The easiest approach is to use an inter-stage transformer with two secondaries, one for each output tube. Two arrangements are possible. The first relies on the output tubes to provide voltage gain. Both secondaries are "grounded" at their respective output tube's cathode. Thus, although the top tube's cathode will swing with the output transformer's primary swing, its grid-to-cathode voltage swing will match that of the bottom tube. Given a 2A3 as an output tube, we will need to develop about 80 volts of peak-to-peak signal across the inter-stage transformer's secondaries to drive the 2A3 to full output. In other words, the driver tube must realize a gain equal to the 40 divided by the inter-stage transformer's winding ratio. (And yes, the 417A can certainly be used, as can the 6N1P.) For example, if the ratio is 1:2, then a gain of 20 is needed.



The second arrangement relies on the driver tube and inter-stage transformer to provide all of the voltage gain. This is a big task, requiring the full output tube's plate swing plus its grid-to-cathode voltage. In the 2A3-based example we have been using, 140 volts of peak drive voltage is needed. Had we been using the 845 instead of the 2A3, the needed voltage would be in the many hundreds of volts. That such a high voltage swing is needed is a direct consequence of using the output tubes as cathode followers.



Notice the top coupling transformer has one end of its secondary grounded. But the bottom transformer has one end attached to the bottom triode's plate. Had this transformer also been grounded, the bottom triode would, first of all, be overloaded by the huge signal present on the secondary and, second, the bottom triode would not active as a cathode follower. The cathode follower works by realizing 100% feedback of its voltage gain and this connection gives the bottom tube 100% of its gain back as feedback.

To understand how the bottom triode is working as a cathode follower, imagine a voltage pulse applied to the output transformer's secondary. This pulse would reflect back into the primary, forcing the top triode's cathode up and the bottom triode's plate down. And since the top tube's grid is referenced to ground, its cathode moving more positive will decrease this tube's conduction. Likewise, the bottom triode's plate's downward movement will be relayed by the inter-stage transformer's secondary, forcing its grid more negative, decreasing its conduction as well. And a negative going pulse would force the output tubes to conduct more. The lower distortion results from the correction of any voltage across the primary not matching the signal across the grids, as any variation from the grid signal provokes the triodes to compensate (by either increasing or decreasing conduction). The lower output impedance results from the triode's rp being reduced by the mu of the tubes. In other words, the output tubes, configured as cathode followers, buck any extraneous voltages on the output, providing a lower distortion and output impedance as a result.

Because of the cathode follower's slightly less than unity gain, we will need to see about 280 volts of peak-to-peak signal across the inter-stage transformer's secondaries to drive the 2A3 to full output. This is a lot of gain, too much for an inter-stage transformer with a low winding ratio. The driver tube must realize a gain, in this example, equal to the 140 divided by the inter-stage transformer's winding ratio. Thus, if the ratio is 1:10, then a gain of 14 is needed. A 300B will require about twice this amount and an 845 will require about five times more gain. Couldn't a much larger winding ratio be used? In general, fear high winding ratios. The higher the winding ratio, the less likely that the secondary's waveform will match the primary's. (I once picked up a nicely built transformer at a surplus store. I assumed it was just a power transformer. But after hooked it up to a signal generator and scope, I was shocked to see perfect square waves at 10 kHz; its winding ratio was 1:1.4.)

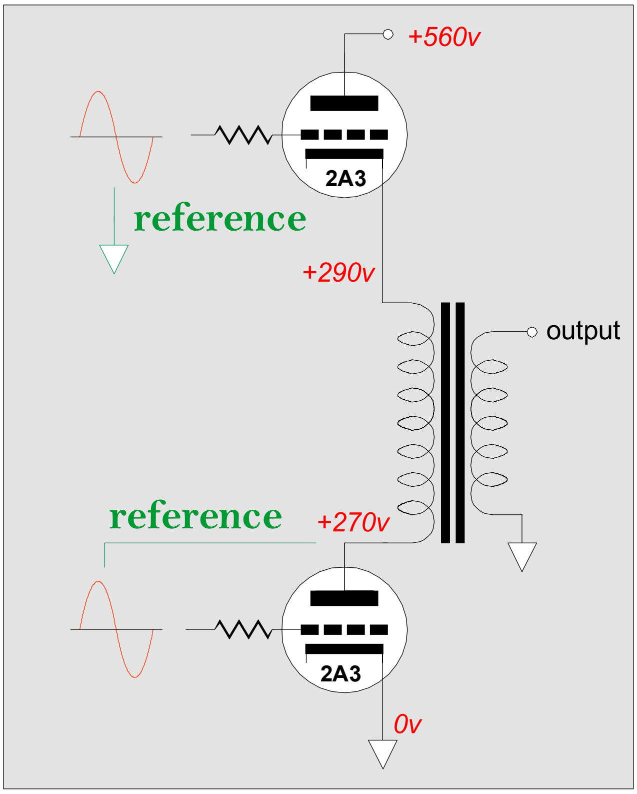
Therefore, it might be best to add additional gain stages in order to retain a modest winding ratio. Please understand that extra gain stages and an inter-stage transformer mean that a global feedback loop is ill-advised, but as the cathode follower configuration already provide both a low output impedance and low distortion, global feedback is probably not needed anyway.

Conceptually, the inter-stage transformer is king. In practice, it has been deposed, replaced by circuitry and coupling capacitors. The main problem with all *high-quality* audio transformers is that they are both expensive and hard to find. Another is that they often pick up noise from stray magnetic fields. But most damning, at least in the eyes of modern engineering practice, is their incompatibility with global feedback because of their limited bandwidth and audio-band phase shifts.

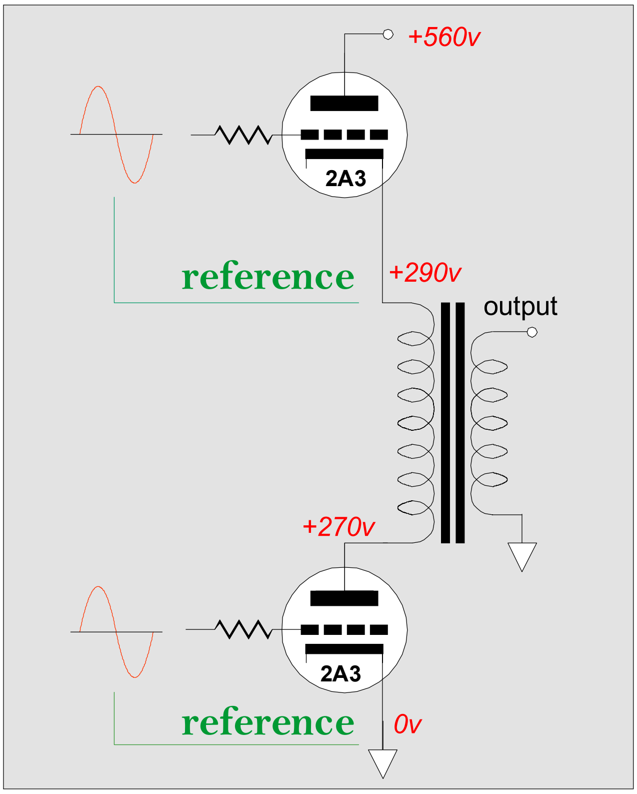
The reference points in the accordion amplifier depend on the output stage's function, either cathode follower or amplifier. Thus, designing a transformerless driver circuit requires a relativistic approach (similar to that used in designing an OTL amplifier), an approach with which few tube circuit designers are comfortable, alas.

(Many designers worship Ground, seeing in it the one and only reference point. They ascribe magical powers to Ground, claiming that Ground can never become noisy or RF polluted, and that Ground, like a black hole gobbling solar systems, can sink infinite current and voltage. When the reference point is moved to some different part of a circuit, these designers grow nervous, their knees weaken and they perspire. Not readily finding a Ground in the circlotron's output stage, they abandon this circuit for the more conventional and safe alternatives.)

If configured as cathode followers, then the reference points are ground for the top tube and the bottom tube's plate for the bottom tube. If configured as grounded-cathode amplifiers, then the reference points are ground for the bottom tube and the top tube's cathode for the top tube.



Cathode-follower accordion amplifier



Grounded-cathode accordion amplifier

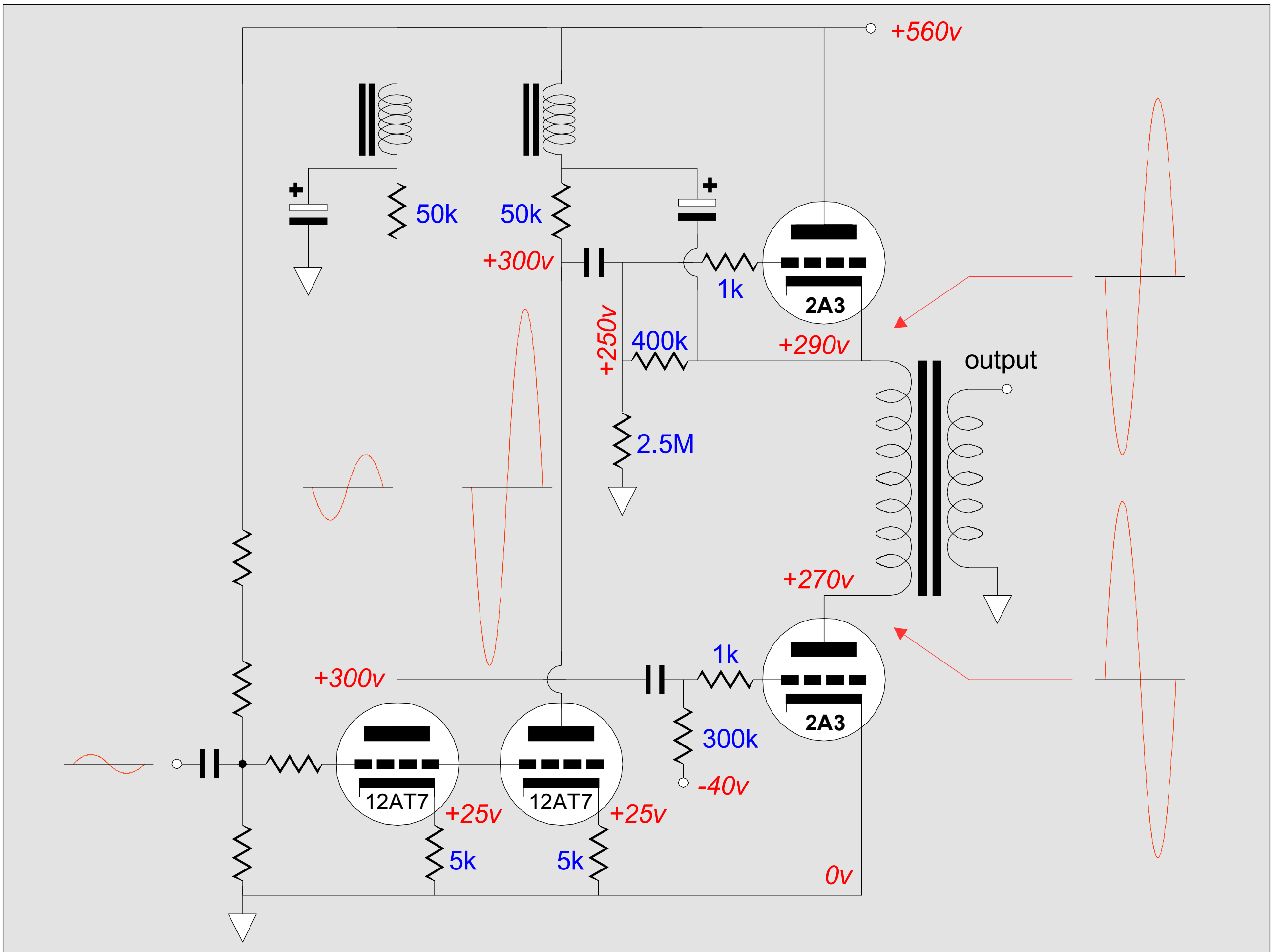
In the circuits above, we see the reference points move from the top tube's input being ground referenced to the bottom tube's input being so referenced. We also see the top tube's cathode serving as a reference as well as the bottom tube's plate. Now, how do we design around these reference points?

The circuit below shows the output stage configured as an amplifier. Each tube sees the same cathode-to-grid signal and each provides gain. Referencing solely from ground, the signal going into the top triode must be much larger than that going to the bottom triode, as the top triode cathode's voltage swing must be subtracted from it. Bootstrapping is the technique used in this circuit to create the huge voltage swing. The capacitor that bridges the top triode's cathode to the driver tube's choke provides the bootstrapping, the positive feedback that allows such gain.

The bottom triode's input receives only the normal gain from the driver tube, about 7 in this example. This means the additional gain must come from an input stage with a gain of at least 6 to drive the 2A3 to full output with an input voltage of 1 volt. The obvious temptation is to use a bypass capacitor across the cathode resistors, as this would greatly increase the gain of the driver stage, possibly eliminating the need for an additional gain stage. Unfortunately, the bypass capacitor would also lower the output impedance of the driver, which would undermine the bootstrapping technique. Without the bypass capacitor, the effective rp is equal to rp plus the cathode resistor value against the sum of the mu plus 1:

rp' = rp + (mu + 1)Rk

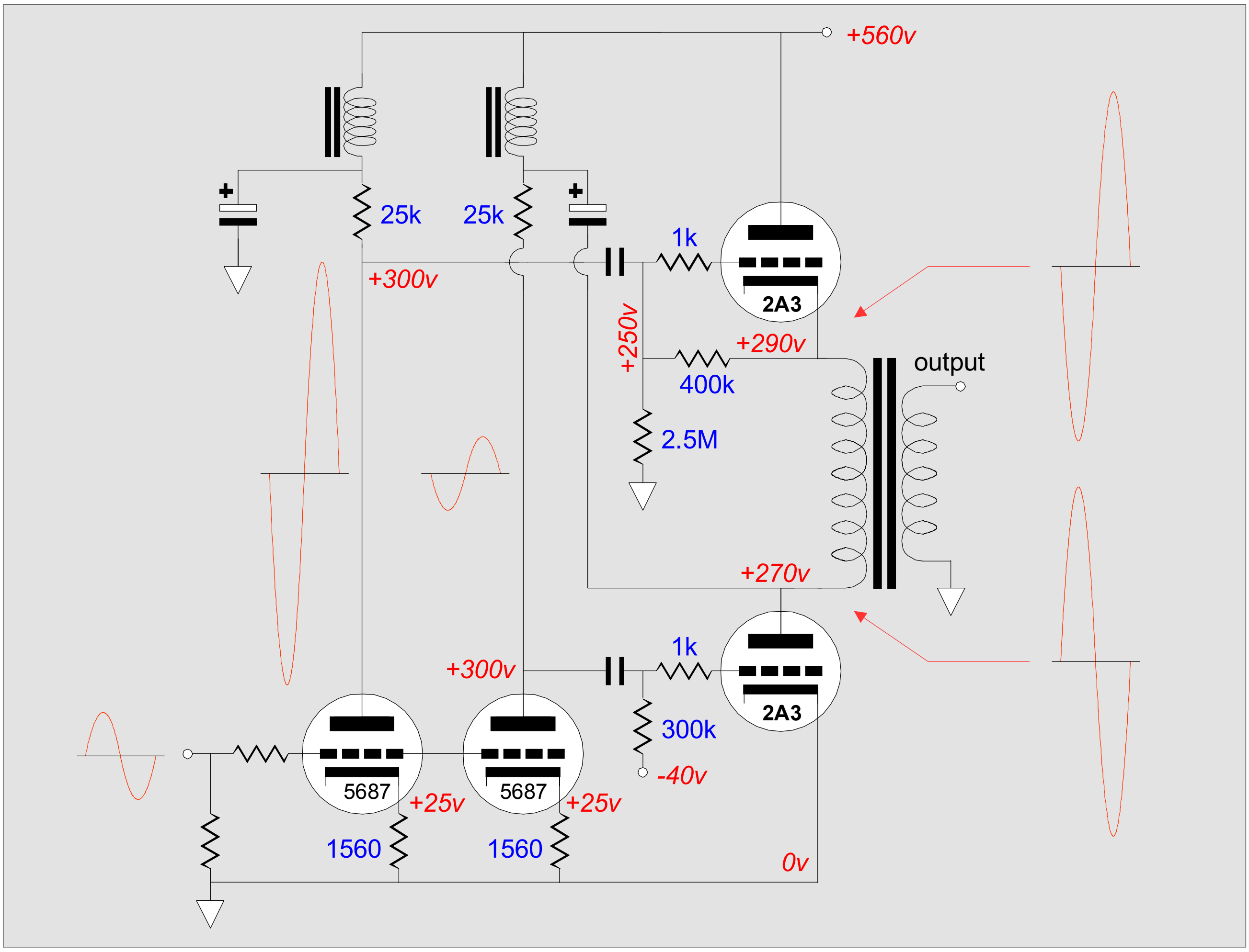
In this example, the effective rp becomes 330k. (Ultimately, the pentode may be a better choice than the triode for the driver stage.)



The circuit below shows the output stage configured as a cathode follower, i.e. no gain, low output impedance, low distortion. Once again, each tube sees the same cathode-to-grid signal; but referenced from ground, the signal going into the top triode is much larger than that going to the bottom triode. This time, however, we must create the required gain the hard way. The capacitor that bridges the bottom triode's plate to its driver tube's choke provides a form of negative bootstrapping, as we need to subtract the plate's voltage swing from the driver stage's voltage swing. If a pulse is reflected back into the output transformer's primary, both tubes will work equally to buck it. The triode's input is ground referenced, so it will naturally buck this pulse. The bottom triode will see the pulse (inverted) at its grid, which will also cause this tube to buck the pulse equally.

Once again, no driver stage bypass capacitors are used, as once again we do not want to lower the output impedance of the driver.

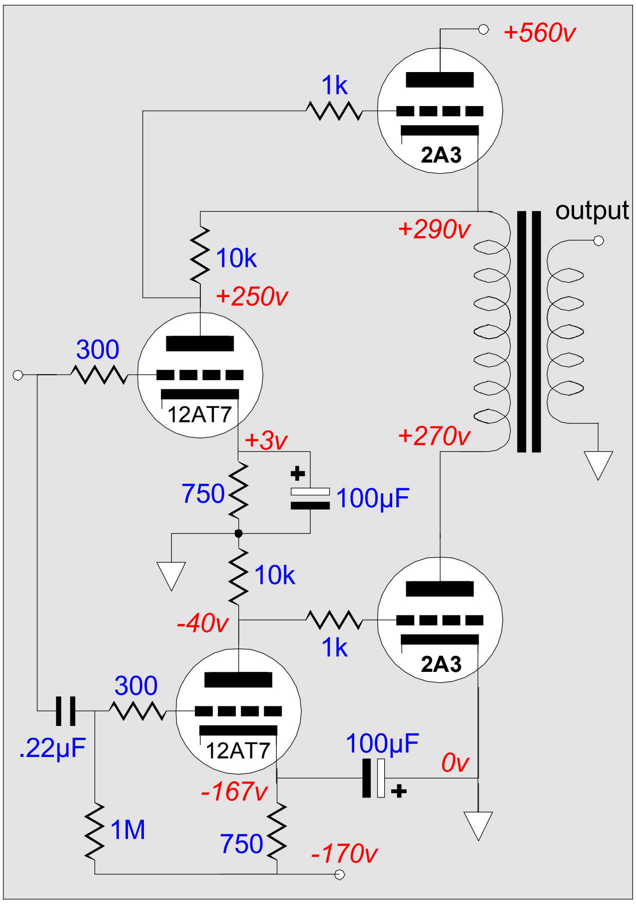
Notice that voltage swings look much like those in the output stage as amplifier example we just covered, the difference being how those voltage swings were created. In our first example, the bootstrapping added voltage swing to the top triode's input. Both tubes actually see the same small driver voltage swing, but the top tube's is magnified. In this example, the bootstrapping subtracts from the bottom triode's input. Both tubes also see the same small driver voltage swing, but the bottom tube's is reduced. Thus, because the voltage swing needed to drive the output stage is so great, and because we cannot rely on positive bootstrapping to artificially create the voltage swing, multiple gain stages are certainly necessary.



The last two design examples used chokes. The chokes served two purposes. The first was to allow the bootstrapping to work without being excessively loaded. The second was to filter the power supply noise from the driver stage. The chokes work well in both functions, but could be replaced by resistors. The main disadvantage to the resistor is that it, unlike the choke, displaces voltage. Making the resistor smaller in value helps preserve the driver's share of the precious B+ voltage, but at the cost of loading down the output stage. Still, eliminating the chokes would be desirable, as good chokes are as hard to find as good audio transformers.

Direct Coupled Accordion

In the circuit below, we have regained the cathode resistor bypass capacitors and lost the chokes and bootstrap capacitors along with the coupling capacitors. Definitely a shopping list of pluses, but what did we have to pay for it?

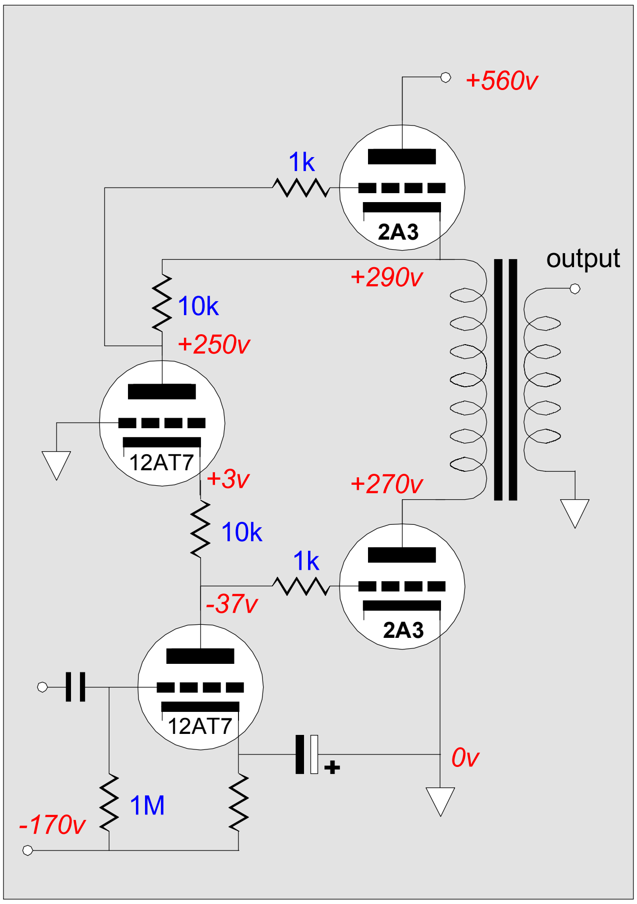


DC cathode-follower accordion amplifier

The price paid is the inclusion of the negative power supply. Negative power supplies are as popular as Mylar coupling capacitors to many tube fanciers. Why? The usual culprits in human affairs are fear and ignorance (greed can be seen as a subset of fear). Many fear complexity; it intimidates. For many the great advantage that tube electronics holds over its solid-state alternative is simplicity. The motto of many audiophiles is "The simpler the better (even if the circuit doesn't work as well)." This explains the overly minimalistic approach to engineering that has become so popular, particularly on the Internet. Grid-stopper resistors, grid resistors, fuses, protective diodes--all have been removed to further the cause of simplicity. The most common failing of a circuit that warrants sending me an email begging for help is oscillation. My answer is to add a grid-stopper resistor -- and the usual reply is "Aren't grid-stopper resistors bad?" Yes, to some extent all components are *bad*, but oscillation is worse, particularly if it takes out your power amplifier and loudspeakers. And certainly negative power supplies subtract from the simplicity these audiophiles desire. The second culprit is ignorance. Many do not understand how a negative voltage is possible at all; isn't that like saying that someone is negative six feet tall? But since the readers of this journal are both brave and informed, we can move forward.

In the circuit shown above, the output tubes are directly coupled to their driver tube's plate. This practice usually runs the risk of damaging the output tubes at turn-on, as the output tube's grid often must see the full B+ voltage until the unit warms up. But in this example, the output tubes are protected somewhat by being in series with each other, as current can flow through either tube only when both tubes are hot and conducting. Furthermore, even if the driver tube is yanked from its socket while the amplifier is in use, the output tubes can only see their grid climb to the same voltage as their cathodes, not the full B+ voltage.

This circuit fails in one truly important aspect: in spite of the symmetry of driver parts, it does not offer an equal drive signal to both output tubes. As configured, the only case wherein the top and bottom tubes see identical drive signals is when the load being driven is 0 ohms. At any higher impedance, the top triode sees less drive voltage than the bottom triode. Probably the easier path to seeing this asymmetry is to imagine a pulse being reflected back into the output transformer's primary. The bottom triode's grid is oblivious to the negative going pulse at its plate, but the top triode's grid sees a small negative going pulse because the driver tube's rp defines a voltage divider with its plate resistor. So the positive going pulse at the top triode's cathode is not relayed in its entirety to the top triode's grid, but rather diminished, making it appear as a negative pulse to the grid. The only way to ensure a symmetrical drive signal is to use triodes with infinite rp's (FETs, MOSFETs, transistors, and pentodes come close). Or another alternative is to effectively increase the rp of the triode used.



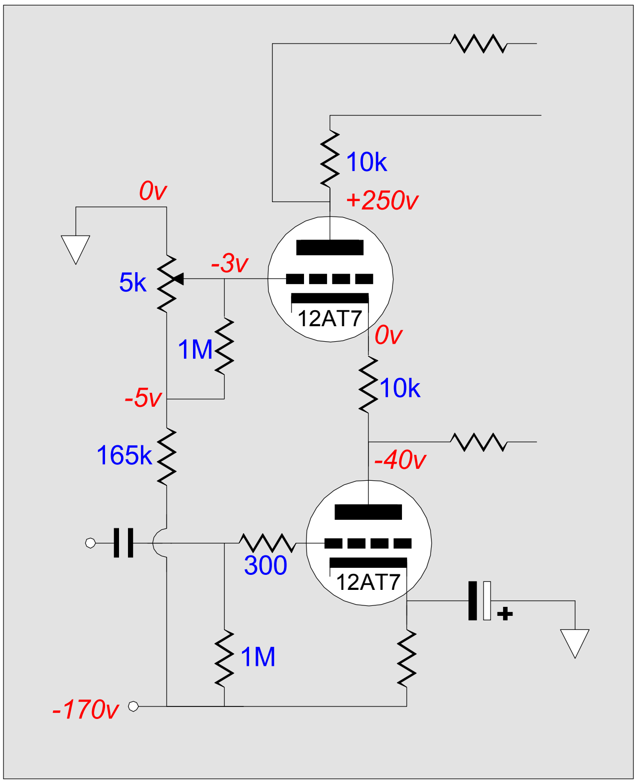
Cascode-like DC driver stage

In the schematic above, we see a cascode-like driver circuit. The bottom triode's gm realizes the voltage gain for both the top and bottom output tubes. With only one current path available to both 10k plate resistors, the signal voltages that are developed across these resistors must match. The driver stage's triodes, however, exhibit very different rp's. The bottom driver triode's rp remains unaltered, but the top triode's rp effectively becomes equal to:

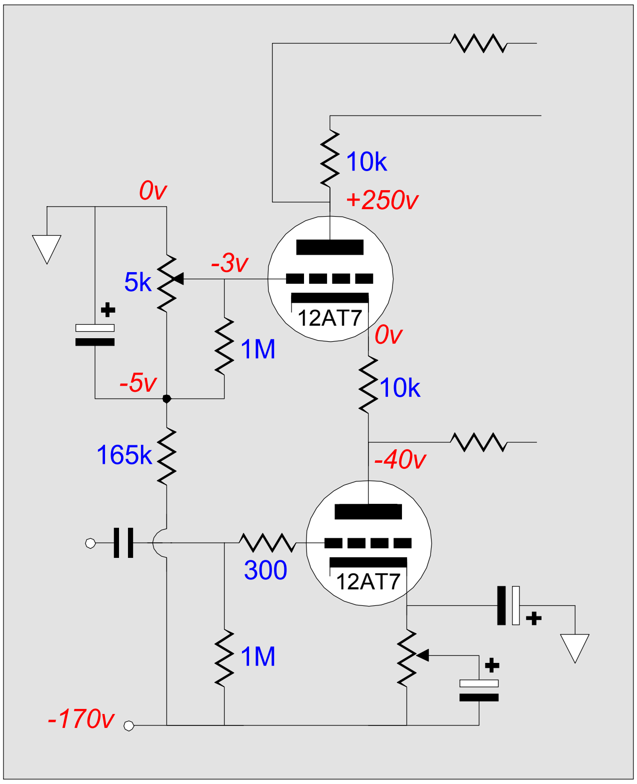
rp´ = rp + (mu + 1)(rp + Ra),

which helps it to approximate the needed infinite value. With such a high effective rp, both top and bottom output tubes present only their rp in opposition to a back-reflected pulse and both equally realize the same voltage gain. Thus, both output tubes function as amplifiers. (Notice that the bottom drive tube's cathode resistor bypass capacitor does not connect to the negative rail, but rather to ground. This arrangement is needed to prevent the negative power supply noise from being amplified. For the same reason, removing the bypass capacitor will result in the negative power supply being amplified.)

There remain two disadvantages of this circuit. The first is the huge voltage differential between driver stage's cathodes, 170 volts in this example. This extreme value makes using a single twin triode envelope less desirable. In fact, the safest route would be to use separate envelopes and to give each its own heater power supply. The second disadvantage is the lack of a means to center the output stages voltage division. What we need is a means to adjust the voltage division between output tubes. Notice that we cannot adjust the idle current balance between the output tubes (something we would strive to do in a parallel single-ended amplifier), as the tubes must share an equal current draw, because they are in series with each other. The easiest solution is to add a potentiometer to the top driver tube's input. This potentiometer will allow a small change in the DC voltage that the bottom output tube will see, which will allow the plate voltage adjustment.

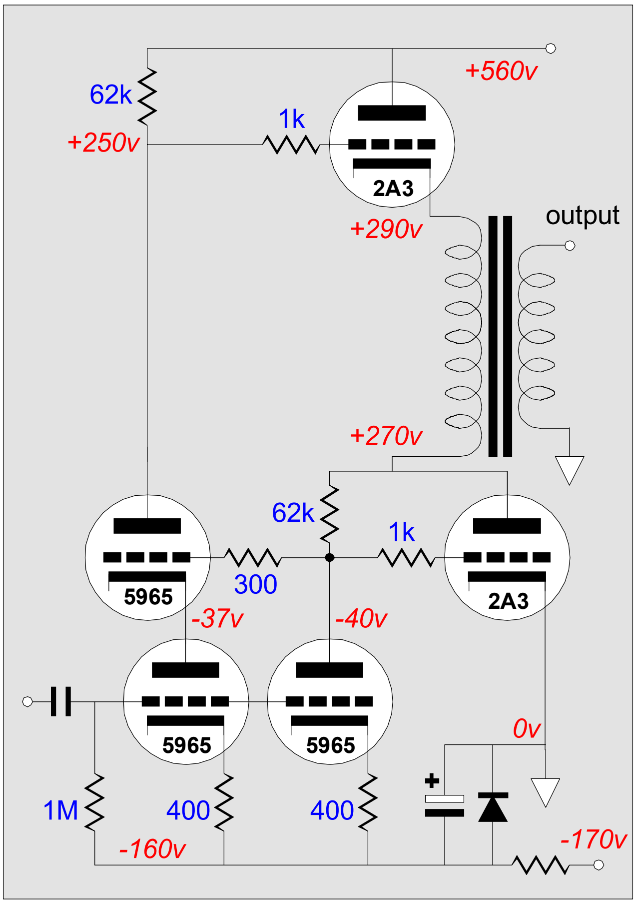


The circuit above shows the adjustment potentiometer in place. With the values displayed, the adjustment range is small, which would work well with matched output tubes.



The next circuit shows the last trick: noise cancellation. The potentiometer that serves as a cathode resistor for the bottom driver tube allows a small amount of negative power supply noise to be injected into the drive signal for the output tubes. Since the power supply noise enters at the cathode, it is not phase inverted at the plate. And because the negative power supply noise is out of phase with the positive power supply noise, the interjection of the negative noise will counter the positive noises influence on the output transformer's primary.

How about the cathode follower configuration? Can a DC-coupled driver be made that functions as well as the amplifier version? Yes, one can be devised, but it requires an additional driver tube. The following circuit illustrates the DC coupling of the output tubes and, appearance to the contrary, this drive circuit realizes the same gain on each leg.



DC-coupled cathode-follower output stage

The top output tube receives its drive signal from the cascode part of the of the driver stage. The bottom output tube, on the other hand, receives its drive signal from the generic grounded-cathode amplifier portion. Although the topologies look different, both portions of the driver circuit deliver the same current gain. When this current gain is applied to the 62k plate resistor that attaches to the B+, the current yields the entire drive signal that the top output tube's grid will see. And when the current is applied to 62k plate resistor that attaches to the bottom output tube's plate, the current yields a drive signal that the bottom output tube's plate movement will undermine. If the bottom output tube sees a positive going input signal, its increased current conduction will pull its plate down, which in turn will pull down the input signal. This means that the bottom tube, like the top output tube, can never realize any voltage gain. But both output tubes do provide current gain, which the output transformer delivers into the load.

Just how both bottom driver tubes manage to maintain an equal current gain is worth studying. Normally, a cascode will realize a much greater gain than the grounded-cathode amplifier. This is due to the cascode preserving much more of the triode's transconductance by preventing its plate voltage from falling. In this driver circuit, the cascode portion does not lock its bottom triode's plate at one voltage; instead, it applies the same voltage swing that the neighboring grounded-cathode amplifier's plate sees. This tracking is accomplished by attaching the cascode's top triode's grid to the grounded-cathode amplifier's plate. Thus, whatever transconductance the grounded-cathode amplifier loses, the cascoded bottom triode will also lose. What complicates seeing the interaction within the driver stage is the 100% degenerative feedback applied by terminating the grounded-cathode's plate resistor into the bottom output tube's plate (terminating this resistor into the B+ would be intuitively much easier to grasp).

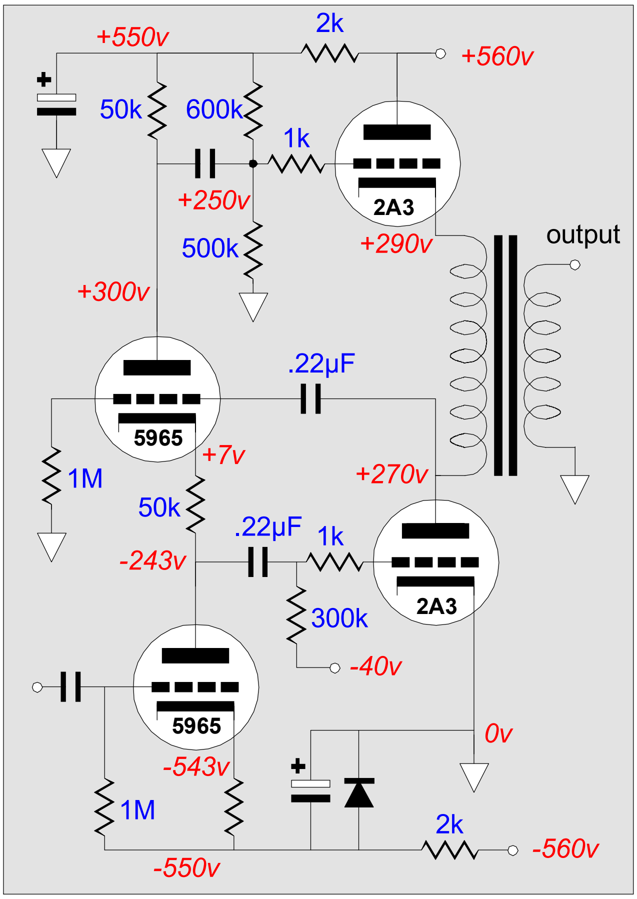
AC-Coupled Cathode Follower Accordion

Once again, we have a two-triode driver stage. In the schematic below, we see once again a cascode-like driver circuit. The bottom triode controls the gain for both the top and bottom output tubes. With only one current path available to both driver tubes and 50k plate resistors, the signal voltage developed across these plate resistors must be equal.

The top output tube is configured as simple cathode follower, with cathode following grid. The coupling capacitor and two-resistor voltage divider establish its DC operating point. The bottom output tube is also configured as a cathode follower in that 100% of its plate's movement is returned to its grid via the top 5965. For example, if a positive pulse is applied to the output transformer's secondary, that pulse will be reflected back into the primary, expanding the voltage across it, and causing the bottom output tube's plate to move down in voltage. This downward movement is relayed to the top 5965 and it too moves its cathode down in voltage, which in turn forces the end of its 50k cathode resistor down in equal measure, turning off the bottom output tube to the same degree as the top output is turned off from having its cathode move more positive relative to its grid. Thus, with both output tubes functioning as cathode followers, both output tubes buck that voltage expansion across the primary.

Note, the bottom driver tube must not have its cathode resistor bypassed, as this tube's rp must be effectively increased to limit the voltage divider action between it and its plate resistor. (In fact, more unbypassed cathode resistance or even a pentode might be needed.)

Especially note that both driver tubes cannot be located in one tube envelope. The voltage differential between the top and bottom driver tubes is a whopping 550 volts, far in excess of any tube's cathode-to-heater rating; two separate envelopes, two separate heater power supplies.



AC-coupled cathode-follower accordion

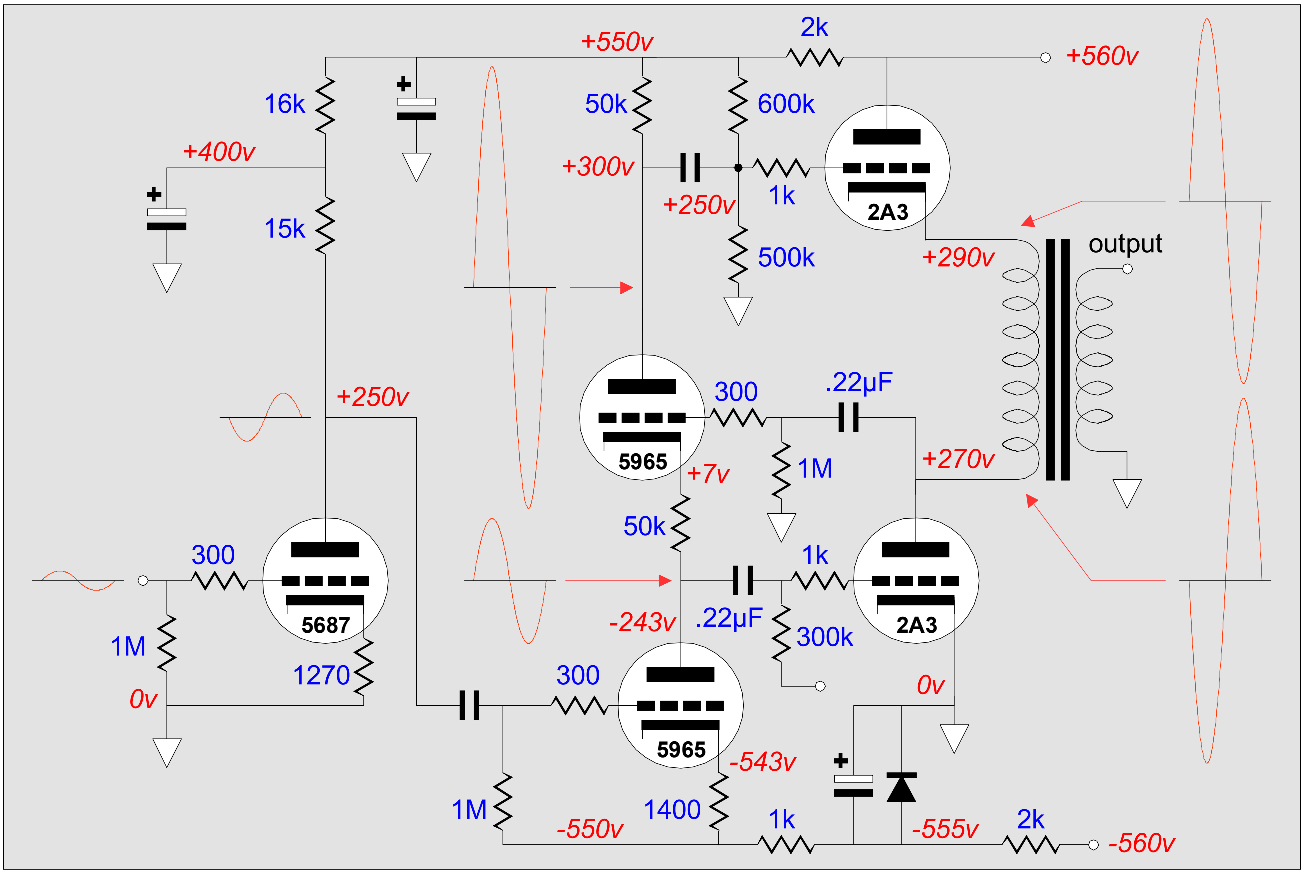
Conclusion

If you expected to read that this amplifier topology is the best possible single-ended amplifier topology, no doubt you were disappointed. This topology, like all other topologies, has its uses, its specific applications that make the best use of its properties, working well into higher impedance loads at higher B+ voltages than the conventional single-ended amplifier.

Our goal should be to fill in the tube audio periodic table of circuits. And when we have done so, we will be in a much better position to design the best tube amplifier *for our particular need*.

On the next page you will find two drawn-out amplifier schematics. These amplifiers make use of only one of the two basic output stage configurations: the unity-gain buffer.

//JRB


+550v
2k
+560v
16k
50k
600k
+400v
+300v
1k
2A3
15k
+250v
+290v
output
500k
300
.22µF
+250v
5965
+7v
1M
+270v
50k
1k
300
5687
-243v
.22µF
300k
2A3
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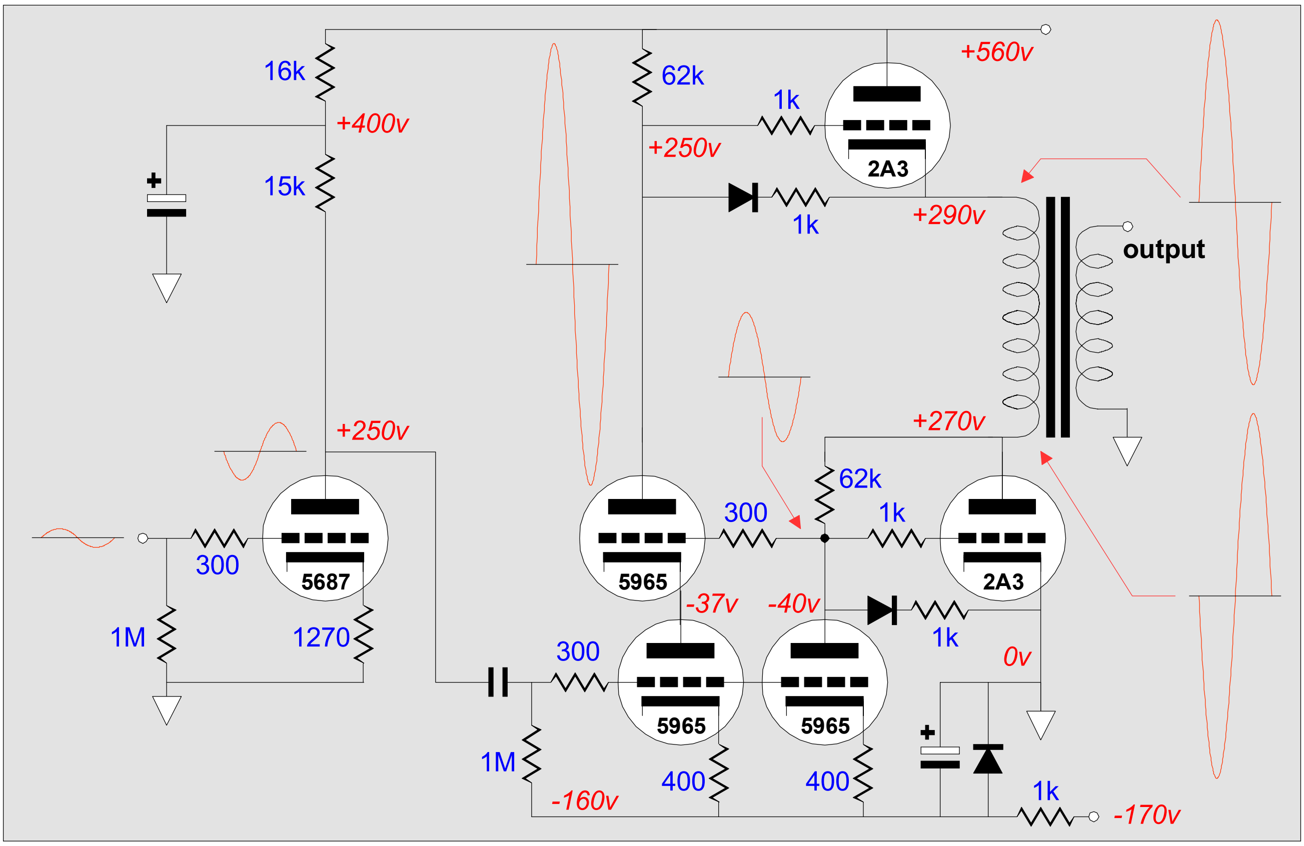
1k
-550v
-555v
2k
-560v


16k
62k
+560v
1k
+400v
+250v
2A3
15k
1k
+290v
output
+250v
+270v
62k
300
1k
5965
2A3
300
5687
-37v
-40v
1M
1270
1k
300
0v
5965
5965
1M
400
400
-160v
1k
-170v

