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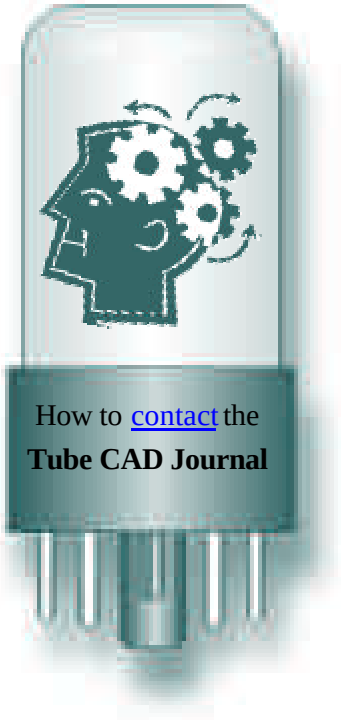
Article

Cars, Planes, and Circlotrons



An Experiment

Many of you miss the old *Tube CAD Journal*, the one that was once published along a fairly regular schedule, the one that held several articles per issue and a readers' letters section. What happened to the old *Tube CAD Journal*?

In spite of over 50 articles, hundreds of schematics and well over a thousand emails, I believe the *TCJ* was never given a real chance to prove itself. It was the Cinderella that only received scraps of time and effort. Since it drained both money and time -- lots of time -- it was resented by family and friends. The *Tube CAD Journal* companion programs did not solve the dilemma.

Thus I have devised an experiment to see if the *Tube CAD Journal* can support itself, allowing me to devote the many hours it would take to publish once again a full journal each and every month; in fact, my goal would be to produce a better journal than the old one. My vision for this reborn *TCJ* includes a strict publishing schedule, optimized PDF format, tube-based audio projects, and the return of reader mail.

Because of the way the Yahoo! Store works, I will have to make this experiment a "limited time offer." So in order to make it something you can buy for yourself and all your tubehead friends for Christmas, Hanukkah, Kwanzaa, Winter Solstice, New Year's, Festivus or any other winter celebration you desire, I will be announcing the experiment the week of the American Thanksgiving holiday (that's the week of November 24th, for those of you outside the U.S.). At that time, you will have four weeks to take advantage of the experiment. Those of you in the *tcj_readers* Yahoo! Group will get an email announcing the offer, but if you are not part of that group, be sure to come back to the website around Thanksgiving to find out for yourself.

- John R. Broskie

Cars, Planes, and Circlotrons

A Letter from Arizona

First of all, a pat on the back for an impressive website. I had heard of the *Tube Cad Journal* years ago, but only recently have I ever visited your site. I followed a link from rec.audio.tubes (you get mentioned there every once in a while, but you never post there, why?) to December 2000 and at first I thought you didn't know what you were talking about…a SRPP circlotron? … a cascaded circlotron? …just not possible. But after searching your site and reading every article and letter that dealt with the Circlotron amplifier, I must conclude that either you don't know what you are talking about or that you are probably the best informed and cleverest tube guru on the net. I've got hours and hours of more reading ahead of me, but my leaning is definitely towards the latter (the late Dr. Gizmo had already come that conclusion it seems.) I do however have one problem with your take on the Circlotron amplifier: you say that the amplifier is functionally identical with the totempole amplifier. In your own words:

> "As for the performance difference between the circlotron bridge amplifier output stage and the totem pole output stage, there is none, as long as the same tubes, the same idle current, and the same drive voltage is provided. I was distressed the first time I saw an electronic textbook treat the two circuits identically. "Wait a minute, these circuits are totally different?" I thought to myself. And they are in terms of ease of setting up bias points and living within the heater-to-cathode voltage limits, but not in electrical terms. The electrons do not know that they are in a long-named circuit: they just flow and their flow is governed by the voltage relationships and impedances in the circuit. To the electron, the both circuits are identical. Our eyes disagree. But then our eyes do not have to move the loudspeaker's diaphragm back and forth."
>
> - August 2001

Sorry, but how can this be so? They are nothing alike. It's like saying that an airplane is functionally identical with a car because they both move passengers from here to there. If you can explain this to me, I'll give you my full endorsement. Anyway, good luck and thanks for the wealth of information on all the other topics.

EJ

Arizona USA

John's Response

First of all, thanks for the pat on the back. No, I don't post to rec.audio.tubes, as I don't read rec.audio.tubes. And while we are at it, thanks for considering me a guru, although I don't think of myself as a guru—well at least not a tube guru. Why not? Well, the tube gurus I've met have disciples (or are ardently seeking them), something I neither have nor want. This quote from Nietzsche, which I always recollect when I read of Adolph Hitler's National Socialists, is germane:

"You would multiply yourself by ten,
by a hundred?
You seek followers?
Seek zeros."

No zeros here. There are a thousand places on the net where tube circuit schematics and tube circuit theory can be found, but this journal's readers are not swayed by gee-whiz enthusiasm, obvious huckstering, magic, or passing fads. Based on the email I receive and the reader's websites I have been invited to visit, I am convinced that this journal's readers are the brightest, most capable tube practitioners in the world.

Nor will gurus restrict their terminology's meanings to those definitions found in a dictionary; instead, the word "drive" will mean voltage or current or gain or power or whatever they want it to mean at the time. Of course, when a word can mean anything, it means nothing (something the universal pantheist never figured out).

Furthermore, like all good magicians, gurus do not reveal trade secrets. I, on the other hand, cannot help but to spill the beans. A bit messy at times, but no beans are left hidden up my sleeve; whereas gurus will not give you any formulas or explanations of their designs. And why should they? How could we ever hope to understand their art, lacking as we do their *secret* knowledge? Without secrets, a guru is as sought-after as an empty ATM.

Now, I will let you in on a little secret...

The Family of Circlotron

As for the circlotron circuit, it's no secret that it perplexes many, if not most tube practitioners. How does the current flow from tube to tube? Why are there two power supplies? Why is it by necessity a class-A amplifier, or must it be? Is it a single-ended or a push-pull amplifier?

In view of all these questions and all the mystery surrounding the topology, I can understand the controversy when I wrote that the much venerated modern circlotron amplifier was functionally identical to the "normal," one-tube-on-top-of-the-other push-pull amplifier. (Next I'll be saying that Allah and God are one and the same. Hmm... When a Christian living in the Middle East prays, does he say "God" or "Allah"? Answer: "Allah," as that is the Arabic word for God.)

Now, let me add fuel to the fire: the circlotron amplifier, not the old classic Wiggins design with output transformers and pentodes, but today's simple version without transformers, in all actuality, after the advertising department's copy has been stripped away, i.e. when examined naked, is no big deal at all. Neither holding magical powers nor breaking any laws of physics, it is as boring (or as interesting, but not more so) a circuit as any totem-pole topology.

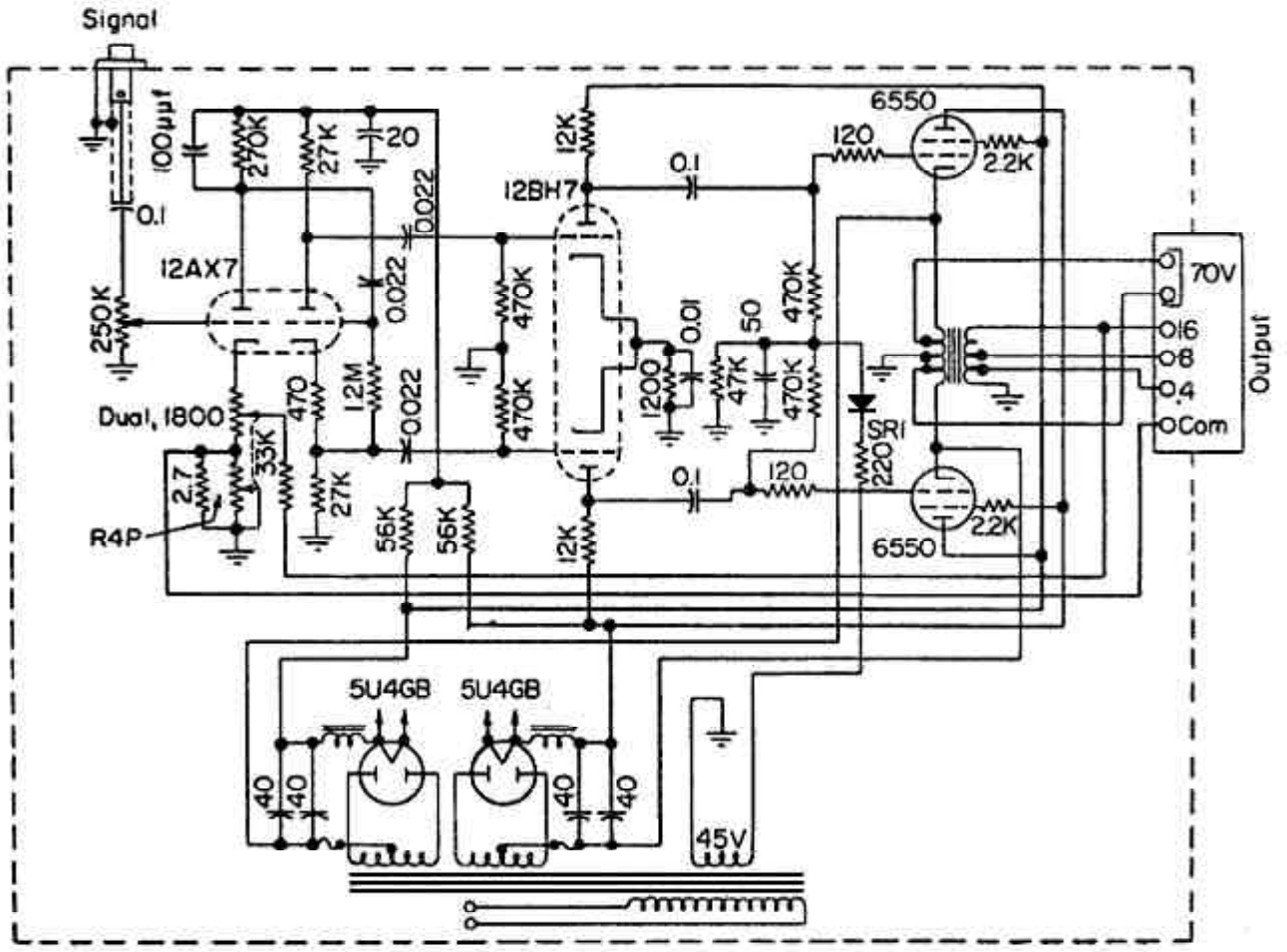
It is, in fact, **the biggest distinction without a difference in tube audio**, which is saying a lot, given the singular, atmospherically-vertiginous, class-A nonsense this topic engenders. This amplifier is just one variation in a family of push pull amplifiers. In this family there are no black sheep or stars, as all its members perform equally well. While the arrangement, the layout, the scheme, the pattern, i.e. the topology of the amplifier may confuse many of us, but it does not confuse the power supplies or the tubes or electrons.

"Heresy! Heretic! Where's the firewood, stake, torch, and angry crowd of audiophiles?" cry they who have a vested interest in keeping circlotron mysterious.

Heresy? First of all, the circlotron amplifier in the original Hall/Wiggins design, the one that used output transformers and pentodes, was an engineering marvel well worthy of praise and interest.

What a beautiful design: two floating power supplies that power the entire amplifier, input and driver stages included; the cross coupling of the driver stage to the output stage; the constant output tube screen voltages, in spite of swinging cathodes. A masterpiece. The only amplifier that should bear the name "circlotron" is this one. On the other hand, the version sold today, the derivative version, the one that uses triodes or triode-connected pentodes and forgoes the output transformer, isn't worth one tenth of the fuss it receives. Not that it is a bad amplifier design; it isn't. It just isn't in any way magical. Let me explain, albeit in a backwards way.

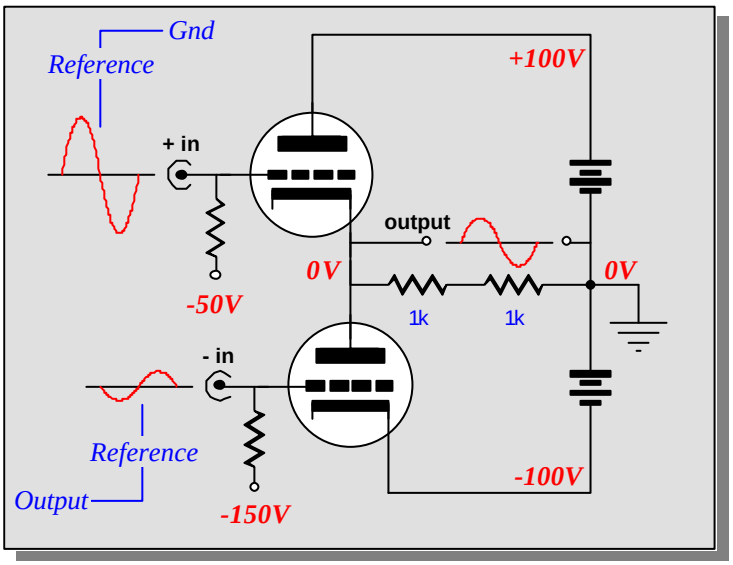
The boring, no-big-deal, totem-pole, one-tube-on-top-of-the-other, push-pull amplifier holds five main components: two large power supply caps (we assume a bipolar power supply), two tubes, and a signal reference (six components, if you wish to count the loudspeaker). These five can be rearranged without changing the amplifier's total harmonic distortion (THD), power output, slew rate, or bandwidth. Rearranged? I've said it before: imagine that electronic circuits are intricate necklaces that use wire to hold all the components together. These necklaces allow a good deal of play, as long as the rules of current conduction are followed, i.e. power supplies are not shorted out, plates are more positive than cathodes.



"Circlotron" 50-watt amplifier, Model A50, with dual power supplies, split load and special output transformer. (*Courtesy of Electrovoice, Inc.*)

In the circuit to the right, we see the classic totem pole configuration. Both triodes, top and bottom, can simultaneously function as grounded-cathode amplifiers or as cathode followers, depending on the driver stage's configuration in relation to the output stage.

In this example, we witness a cathode follower functioning from both output tubes, hence the larger input signal swing for the top triode than for the bottom, as the top triode's cathode must follow in phase the output signal and while the bottom triode's cathode is effectively grounded through the large power supply capacitor to ground, the driver stage will return output to the bottom triode's grid, so that it too will function as a cathode follower. (Whenever you are evaluating a circuit's AC operation, imagine that the power supplies and capacitors have been shorted out with wires, as they effectively are dead shorts to AC signals, at least to high-frequency ones.)

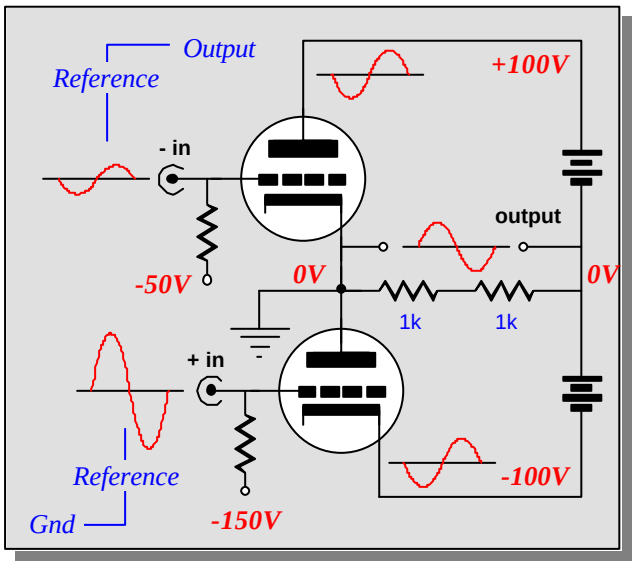


Generic one-tube-on-top-of-the-other push-pull class-AB amplifier

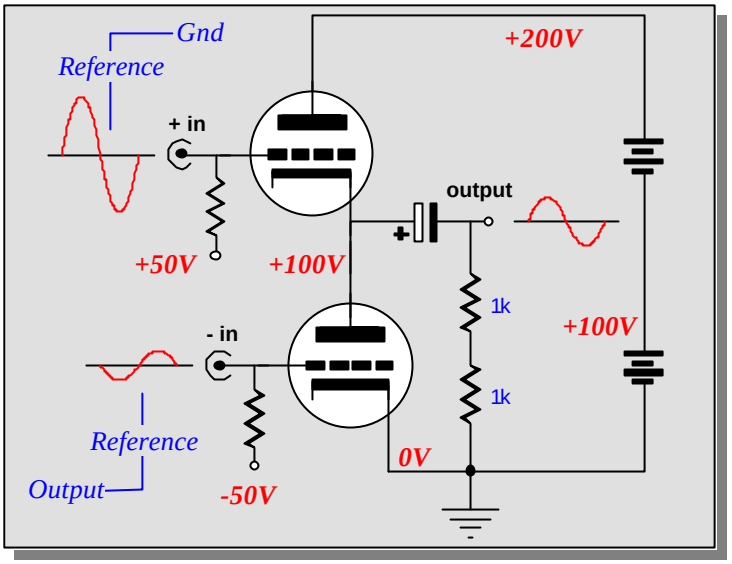
In the next circuit, see the same basic topology varied slightly (or hugely, but familiarity has jaded us too much to see it so). The signal reference point has been shifted from the power supply's midpoint to the bottom triode's cathode. Few would regard this change as being worthy of controversy, as the amplifier functions identically to the previous version. (Although, there would be some controversy surrounding the use of a coupling capacitor on the output.)

Understand, however, that there is no controversy about how these variations on a the basic circuit work, no magic, no physics defying stunts, just pure vanilla circuitry. They are purely push pull designs that can be biased to work in class-A, class-AB, or class-B, but are usually biased in a lean class-AB, because of the high plate voltages. No one claims that they are, in fact, two single-ended amplifiers in parallel (or single-ended amplifiers in series) or that they must be, by necessity, class-A amplifiers.

Now, let's make things a bit more interesting: let's move the ground reference once again; this time, to the top triode's cathode. In this variation shown below, once again the same cathode follower functioning has been retained, thus the larger input signal swing for the bottom triode than for the top triode.



Generic one-tube-on-top-of-the-other push-pull class-AB amplifier with the signal reference shifted to the other side



Generic one-tube-on-top-of-the-other push-pull class-AB amplifier with the signal reference shifted to the bottom triode's cathode and with a unipolar power supply

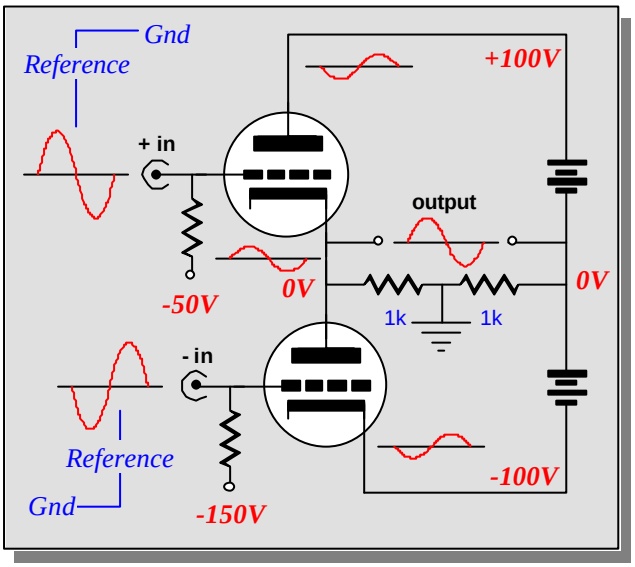
Wait a minute, how can this be? Since the top triode's cathode is now quite literally grounded, how can it function as a cathode follower? If the driver stage returns all of the top triode's voltage gain to its grid in anti-phase, then the triode functions as a 100% negative degeneration amplifier, whose most common realization just happens to be the classic cathode follower topology, but not necessarily so. Appearances are not as important as voltages and current flow.

Once again, the tube doesn't know that it is in something called a "cathode follower" or a "cascode" or a "SRPP;" it only "knows" that its cathode-to-plate voltage is such and such an amount and that its cathode-to-grid voltage is such and such an amount. And in response to the changes in cathode-to-grid and cathode-to-plate voltages, it conducts either more current or less current. This strict determinism disheartens and frightens those who believe in freedom of will for electrons, but it is essential to understanding how circuits work.

Here is an analogy that might help: when Copernicus shifted our solar system's reference from Earth to the Sun, the planets were oblivious to the shift and they blindly continued along their paths as if nothing had happened. We were not so lucky, as least one man was burned at the stake as a result.

So, what have we gained from moving the reference to the other side? Other than confusing many, nothing, absolutely nothing. The gain, Zo, PSRR, distortion, and bandwidth remain unchanged, in spite of the power supply floating up and down equally with the output signal. (Of course, there might be clever input and driver stage tricks that could be implemented with this variation that would not be possible with the generic version, with its fixed power supply, but that is not relevant to how the basic output stage topology functions.)

Now, let's move the reference point again. Continuing our clockwise movement, this time to the center of the output, via a two-resistor voltage divider.



Reordered one-tube-on-top-of-the-other push-pull class-AB amplifier with the signal reference shifted to the center of the output and the power supply is left floating, i.e. it is not directly connected to ground

This new variation above will probably cause a lot of head scratching, as it seems only slightly different from the original, but very, very wrong, like a tennis match on top of a teeter-totter.

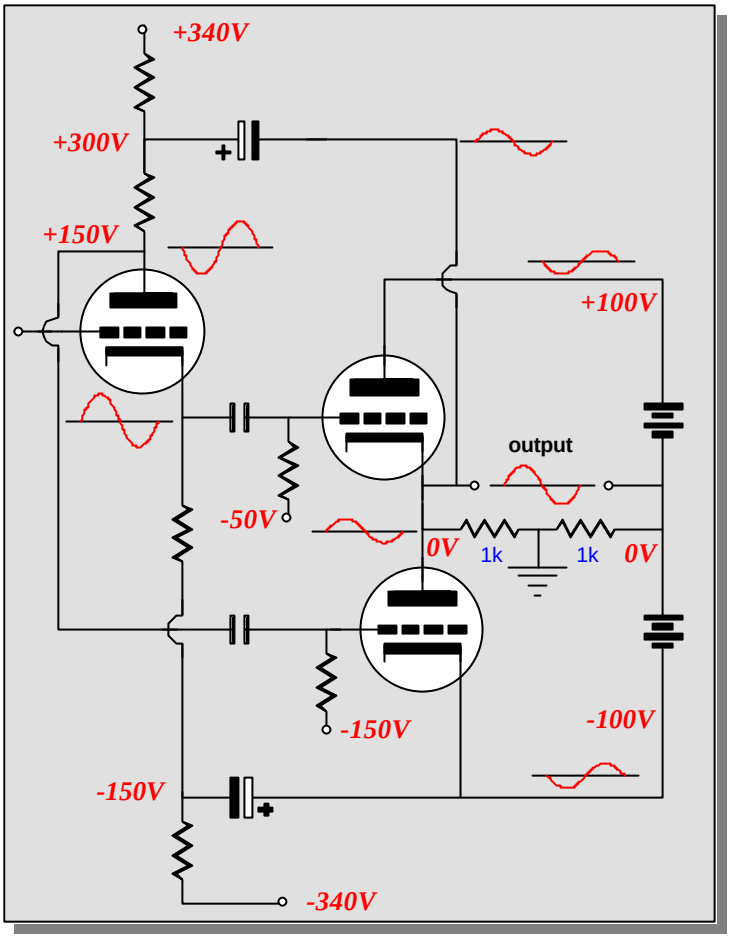
The two-resistor voltage divider splits the output signal and fixes ground at that point. The power supply is left floating and it moves up and down with the output signal, although by only half as much as in the previous variation. Once again, both triodes function in the signal degeneration mode (ala a cathode follower). Once again, the gain, PSRR, distortion, and bandwidth remain unchanged.

(Truly observant readers will have realized that output impedance did not make the list of shared attributes this time. More on that later.)

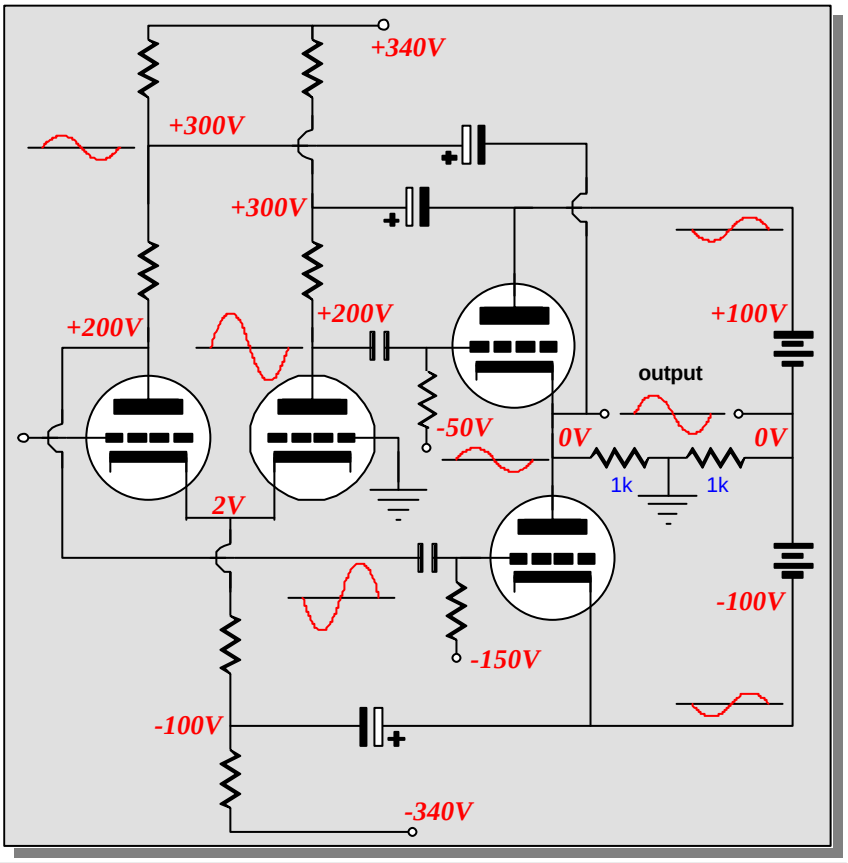
Notice, however, that the drive signals for bottom and top triodes are now equal in magnitude. In both previous variations, we had favored one triode over the other, but not here, as each triode shares the same claim over the output stage's reference. (The sad fact is that many tube practitioners think that this new topology and its functioning are identical to the original totem-pole topology. Why otherwise would they be so oblivious to the two different signal reference points in the original totem-pole amplifier, as evidenced by their delivering the same grid voltage swing to the top and bottom tubes?)

Amazing what we can do with two resistors and re-soldering one wire. Now let's rearrange some other circuit elements. The triode, which is a modified diode at heart, can only conduct current when its cathode is less positive than its plate. Thus, we cannot invert the triode's relation to the power supply, (well, we could, but the triode would cease to conduct) but we can swap the positions of the bottom triode and bottom power supply.

Spilt-load phase splitter configured to eliminate power supply noise from the output of the vertical center-referenced push-pull amplifier. The bottom triode's grid must see the same amount of noise as its cathode to null the noise at its plate. This configuration injects the negative rail power supply noise into the phase splitter's plate circuit, but not its cathode circuit.



Long-tailed phase splitter configured to eliminate power supply noise from the output of the vertical center-referenced push-pull amplifier. The bottom triode's grid must see the same amount of noise as its cathode to null the noise at its plate. This configuration injects the negative rail power supply noise into the phase splitter's first (left triode) plate circuit, but not the second triode's plate, as anti-phase power supply noise is injected there as well and cancels, yielding no power supply noise at the second plate.

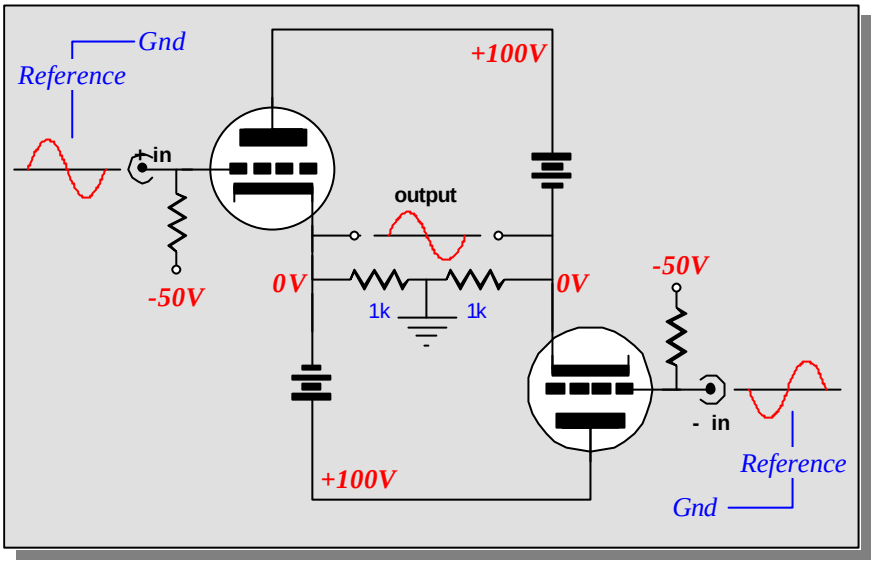


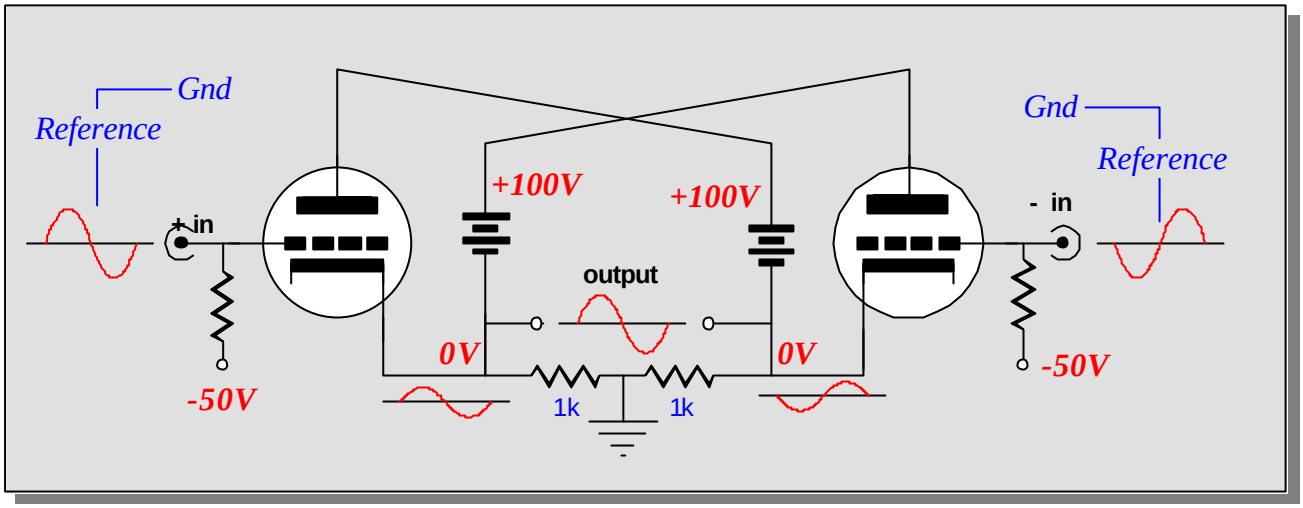
Think of it as the power supply leap frogging the triode. (Two power supplies will be needed in this example, but as each hold only half the power delivery as the one they replaced, no net increase or decrease in power supply strength results.)

If the next circuit does not look familiar, it should, as it is the circlotron of high-end audio fame. (In your mind's eye, bend and fold the bottom half of the circuit up and the familiar figure eight configuration will become apparent. If you need help, see the top of the next page.)

Note the similarity in drive signal strengths between circlotron and the last circuit, with one tube atop the other. The reference point falls at the midpoint of the output signal in both cases; the output triodes in both amplifiers function with same amount of signal degeneration at their cathodes (once again, much like cathode followers); and in both circuits the same voltage and current gain and output impedance are realized, as the triodes all share the same cathode-to-plate voltages and transconductance and see exactly the same IV dynamics.

Generic one-tube-side-by-side-the-other push-pull class-AB amplifier with the signal reference shifted to the center of the output, a.k.a. the Balanced amplifier or the Circlotron amplifier





Generic circlotron push-pull class-AB amplifier with the signal reference at the center of the output

As far as the triodes are concerned, they are in the exact same circuit, as nothing has changed, the same voltages and the same currents.

For example, imagine placing a 2-volt battery across the outputs of these two amplifier topologies. In the first amplifier, the top triode's cathode will be forced positive by 1 volt and the power supply's center point will be forced negative by 1 volt, which will in turn force the bottom triode's cathode negative by 1 volt. The result is that since none of the grids have shifted in voltage, the top triode sees a 1-volt more negative grid voltage and it conducts less; the bottom triode, a 1-volt more positive grid voltage and it conducts more.

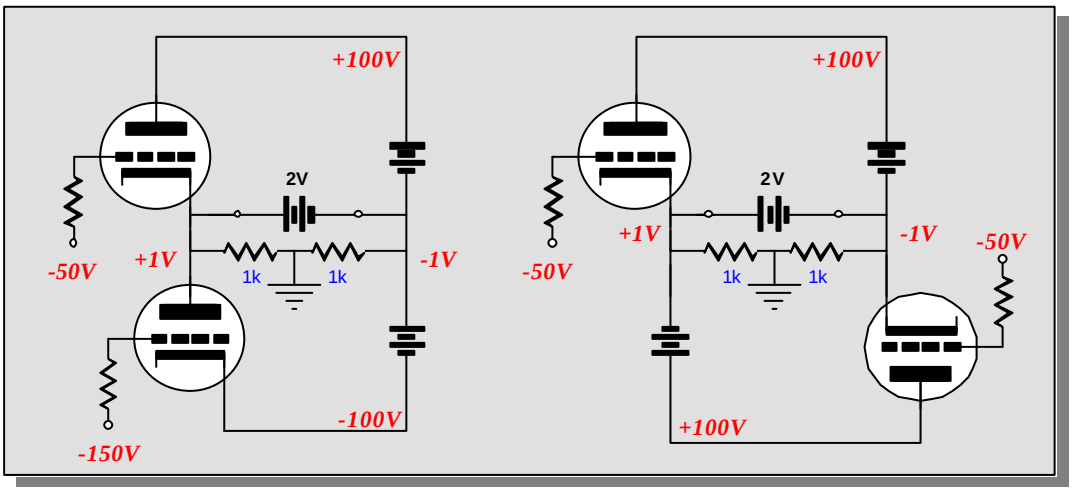
This then pulls the bottom triode's plate down and top triode's plate up. In other words, the tubes strive to correct the battery's voltage across the output, their transconductance powering their efforts. In the circlotron amplifier, the same battery across the output causes the exact same result, as one triode conducts less while the second conducts more, striving to nullify the battery's voltage.

Notice that in both cases that each triode only saw half of the battery voltage (1 volt) and in anti-phase to each other, which makes sense as the reference falls exactly half way between the output terminals of the amplifiers. Notice also that in both cases each triode saw the entire battery voltage (2 volts) superimposed on its cathode-to-plate voltage, negatively on the first triode, positively on the second triode.

In both amplifiers, the battery experiences a current flow when hooked up across the output terminals and the amount of current that flows through the battery is directly related to the output impedance of the amplifiers. For example, if 1 ampere of current flowed, then the amplifier has an output impedance of 2 ohms, as I = V/R, or in terms of R, R = V/I.

Let's pause and consider this: as both amplifier topologies share identical characteristics, has just adding two resistors and shifting the ground magically transformed the vanilla, push-pull, very lean running, class-AB, totem-pole amplifier into a single-ended, class-A, magic-imbued amplifier?

2-volt battery placed across the outputs of the push pull amplifiers to test the amplifier's output impedance



If so, rush to the patent office, but first come up with a new name as everyone knows that you *can* judge an amplifier by its title. For example, when the phase splitter that was used in countless Audio Research amplifiers was called the "cross-coupled phase splitter," no one cared and it was considered somewhat dead sounding, but now that it is known as the "Van Scoyoc phase splitter" it is much more interesting and better sounding as well.

But which name? "Mega-path" or "Ultra-Mega-Path" or "Megacirc" or "Ultratron," yes that's it: the Ultratron amplifier; single-ended-class-A glory by the wave of a tongue.

What a joy it is to live in an age of miracles and magic, unburdened by logic and unfettered by common sense. Fifty years ago, people were not so lucky. Back then, most people did not believe in astrology and UFOs. In fact, tube circuitry was still taught in universities and libraries were filled with solid, well researched pages devoted to the vacuum tube and its functioning. In those bleak days, many of the brightest, most capable scientists and engineers devoted themselves exclusively to understanding how a tube worked in a circuit; and we all know what party poopers those kinds of people are.

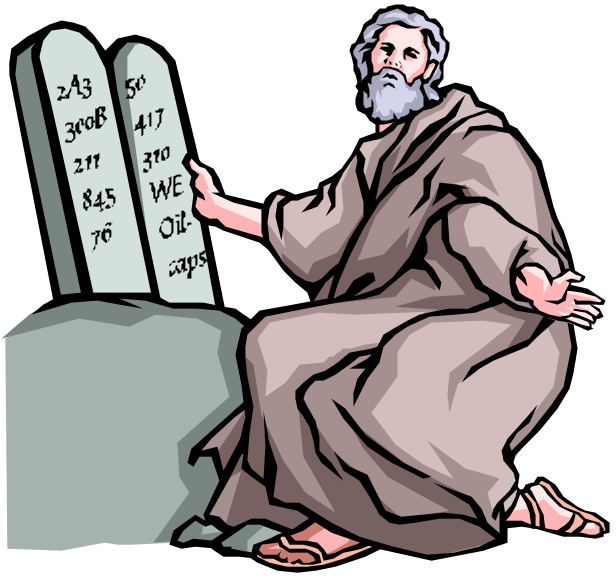
Imagine if a time capsule had a reverse gear and that we could send the pearls of today's better understanding of the vacuum tube back to the fifties. Here's the scene: the oppressively stolid electrical engineer, the one with Buddy Holly glasses and white socks, finds what looks like a thermos on his desk. Opening it, he finds a single sheet of paper upon which is written the following:

> 300B*, 2A3, 45, 76, 211, 845, carbon resistors and oil capacitors, single-ended and push pull transformers, circlotron with triodes, tube rectifiers, octal tubes, connect the power supply capacitor to the output tube's cathode.
>
> * actually anything at all marked Western Electric including lamps and doorstops

Of course, so dense a dollop of wisdom might be too much for any one human being to absorb without passing out (I felt a bit queasy just typing the list). It would be as if Mozart were presented with a performance of John Cage's famous composition *4'33 (of Silence)*. Really, it's truly amazing that so much has come from so little. Or maybe… confusing our list of received truths for someone's old shopping list, the engineer would hurl it in the garbage. Alas, we will never know.

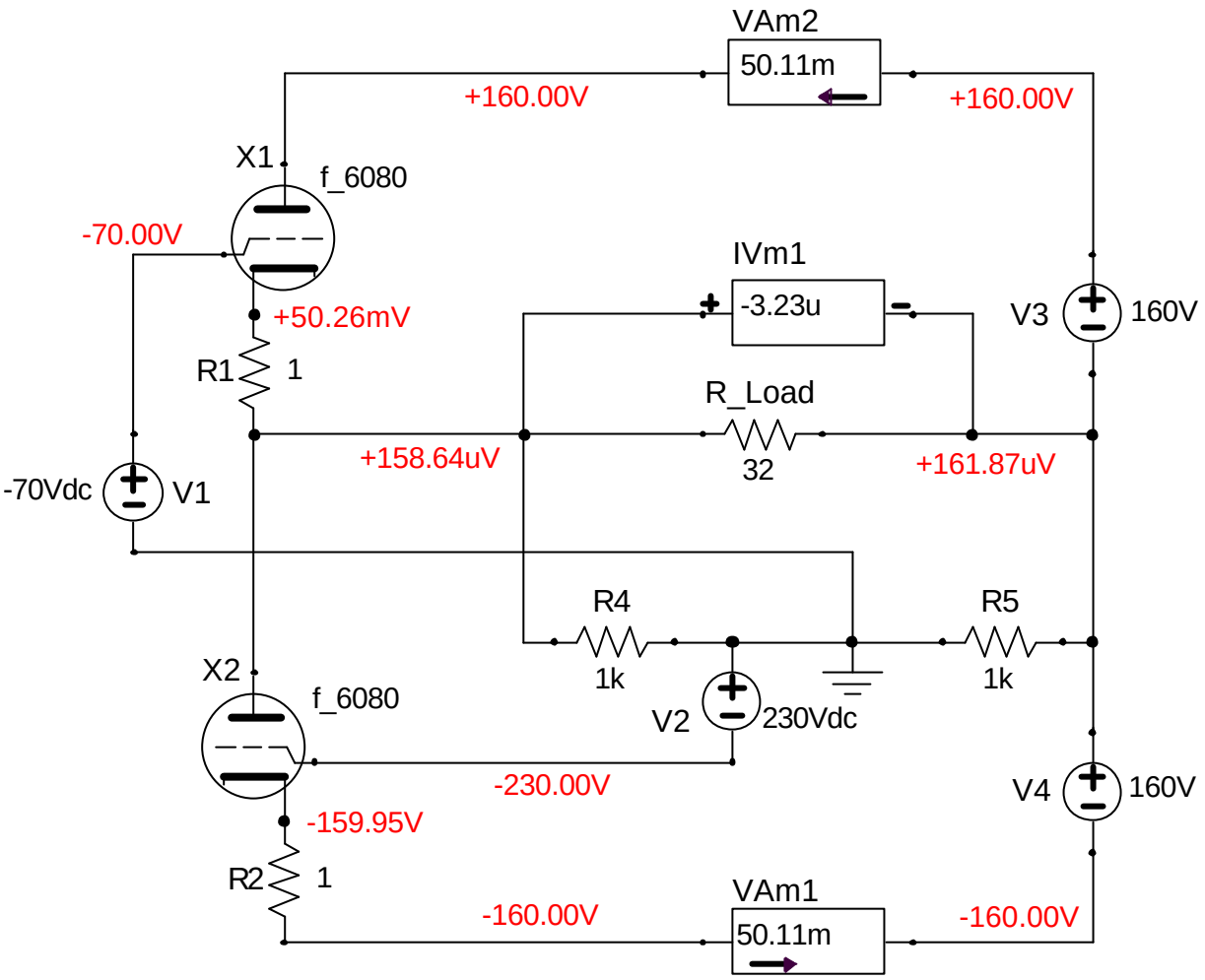
Wait one sarcastic, solid-state-loving, I'm-not-as-trendy-as-thou minute: how do we know that these two amplifiers do in fact function identically?

Well, one could derive all the formulas for gain, Zo, PSRR, bandwidth, and distortion for both amplifiers and then compare the formulas (this is my preferred path, as it can be done on the back of an envelope, while eating cereal). Or one could actually build two amplifiers and test both for gain, Zo, PSRR, bandwidth, and distortion. Or, lastly, one could model both amplifiers in SPICE and compare results, which is what we will do next, as it requires the least amount of work (it's hard to format the back of an envelope for the internet).

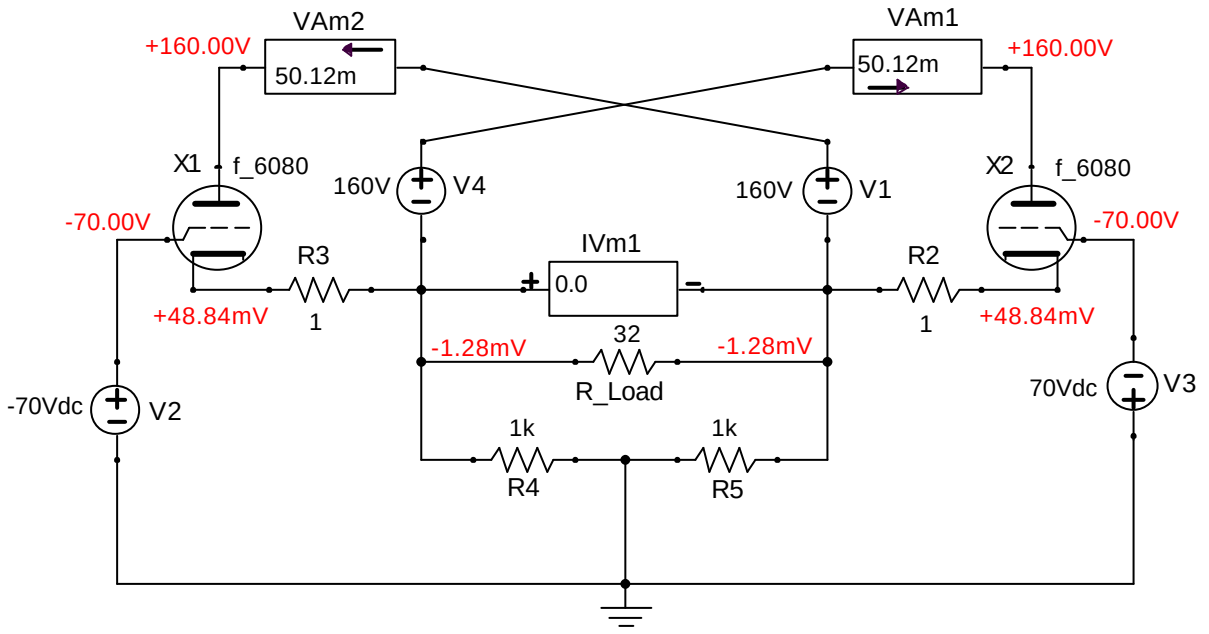


On the next page, we see the totem-pole amplifier with the center-shifted reference point modeled in B2 Spice A/D. This amplifier uses 6AS7 tubes and a 32-ohm load resistance, which implies that four 6AS7 type triodes would actually be used per phase leg.

The secret to using SPICE successfully is to realize that you are not playing a game of *The Sims*: you do not want as much detail and reality mapping as you can get. Instead, you only want to get the same *results* that reality would give; hence the SPICE op-amp models that hold only a few transistors, not the several dozen that the real op-amp holds. A SPICE model that held a perfect 1:1 representation of reality would as useful and cumbersome as a map of New York City likewise rendered in a scale of 1:1.



SPICE schematic of one-tube-on-top-of-the-other push-pull class-AB amplifier with the signal reference shifted to the center of the output and the power supply is left floating



SPICE schematic of one-tube-next-to-the-other push-pull class-AB amplifier with the signal reference shifted to the center of the output and the power supplies are left floating, the a.k.a. circlotron

As 32 ohms divided by 4 equals 8-ohms, rather than burden the SPICE engine with eight 6AS7s, we'll use only two 6AS7s but increase the load resistance by fourfold. (The 1-ohm cathode resistors are a small insurance policy against the triodes running into excessive current conduction and could be removed without altering the circuit's functioning in the least; but I would not recommended it, as these tube are notorious for burning up—in fact, a 4 ohm resistor would be safer still.) This amplifier has a gain of 0.33 and puts out 28.5 volts just before the grid goes positive relative the cathode, which equals 12.7 watts into the 32-ohm load and, when the full array of output tubes are used, 50 watts into an 8-ohm load. The output impedance is 30.5 ohms for one pair of 6AS7s and 7.6 ohms for a pair of 6AS7 quartets. The THD is 3.37% and the harmonic distribution is shown below. (Typical push-pull harmonic structure.)

And now for something completely different, let's see what the modern circlotron has to offer in opposition to this clunky, push-pull, class-AB amplifier.

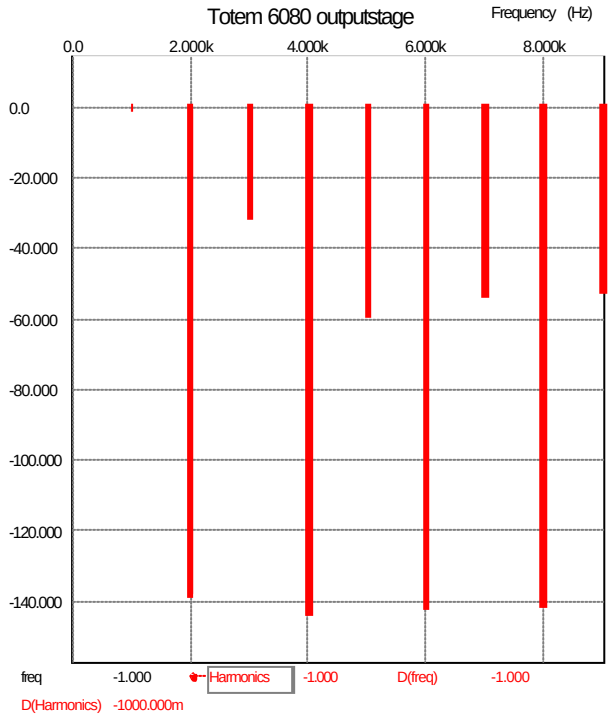
The amplifier has a gain of 0.33 and puts out 28.5 volts just before the grid goes positive relative the cathode, which equals 12.7 watts into the 32-ohm load and 50 watts into an 8-ohm load, with 8 output tubes. The output impedance is 30.5 ohms for one pair of 6AS7s and 7.6 ohms for a pair of 6AS7 quartets. The THD is 3.37% and the harmonic distribution is shown below right. (The only difference I can spot is at the 2nd and 4th harmonics.)

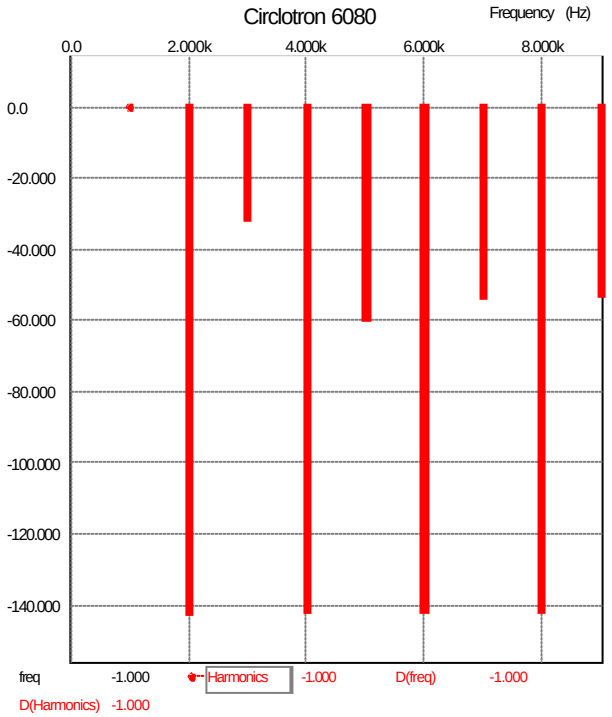
Note the 100% classic push pull signature: even harmonics are notched out and odd order harmonics predominate (lots of odd order harmonics in this example, much like a transistor amplifier). There isn't a single ended amplifier in the world that has a harmonic structure like the one shown below (or sounds like this amplifier). Well, so much for the widely imputed single-ended aspect of the modern circlotron.

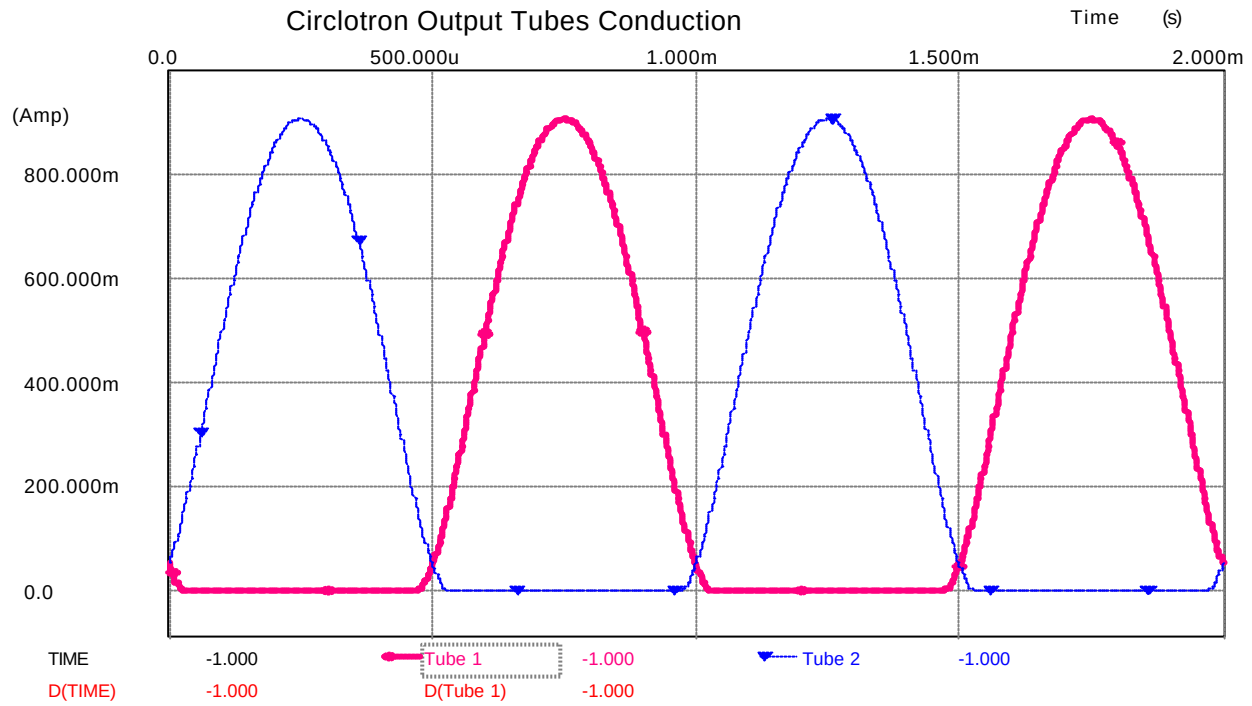
Or, if more proof is needed, look at the current conduction through each triode in the graph on the next page. Once again, one-hundred-percent-classic-push-pull operation. Notice how the class-A overlap only extends to twice the idle current, about 100 mA or about half a watt into 8 ohms with 8 output triodes. Well, so much for pure class-A operation by necessity. But couldn't the idle current be increased to further the amount of class-A operation? Not by much, as the triodes are already dissipating 8 watts each, so there isn't much safety headroom left to go.

What happened? One dB at –140 dB (1/10,000,000) is no difference (probably a SPICE engine error do to 1G-ohm node shunts), at least no difference worth arguing over. Where did the magic go? All we have left to the amplifier that stood so tall is a crummy, miserable push-pull, class-AB amplifier that topologically isn't that different from the cheap solid-state amplifiers from the 60s.

Wait another minute; how do we know that the SPICE engine isn't rigged to show no difference between these two wildly differing amplifiers? That's possible isn't it?







Circlotron output tubes conduction over two cycles. Single ended? Push pull? Class-A? You decide.

Well actually, I did once read in my horoscope how this UFO had landed on the UC Berkeley campus and how it had forced a few grad students to rewrite the code used by the SPICE engine so that…


New Circuit: the Clonetron

Returning to earth, at least six different amplifier topologies can be had from two large power supply caps, two tubes, and a signal reference. We have seen four so far. The remaining two are variations on the circlotron circuit.

In the first as shown on the top of the next page, we shift the reference to the left output terminal and, in the second, to the right terminal. Once again, after the driver circuitry has been updated to work with the new reference points, the amplifiers perform identically with the other variations, offering the same gain, distortion, and bandwidth. But not output impedance. Both the totem-pole configuration and the circlotron configuration whose signal reference lies midway across the output have higher output impedances than the four other variations. Why?

The reference point is used by the output tubes countering any grid-to-cathode voltage perturbations. So when we placed the signal reference at the midpoint of the output, we effectively halved the transconductance that the output tubes use to oppose perturbations at the output, as each grid only sees half of the perturbation voltage.

So is the output impedance exactly half that of the other four variations? It is, if the triodes used have an infinitely high mu. While the transconductance has been halved, the each triode's rp remains constant and the two rp's are effectively in parallel with the output load impedance. Put mathematically,

Zo = rp/(mu +2),

which when contrasted with the formula for the other four variations,

Zo = rp/(2[mu +1])

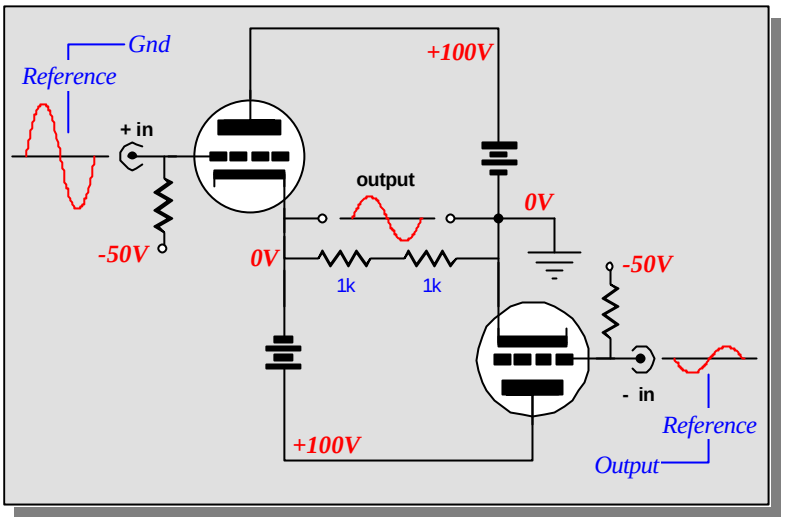
yields the following ratio

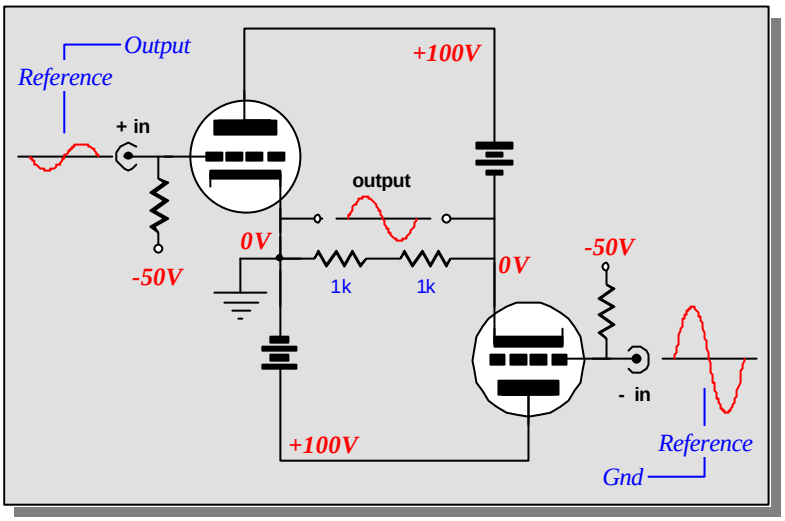
Ratio = (mu +2) / (2[mu +1]).

Thus, as mu approaches zero, the difference between variations climbs to none (or rather, unity; in other words, there is no difference); as the mu approaches infinity, the difference between variations falls to half (50%). Now, the 6AS7 is an interesting triode, in that its mu is only 2, almost nothing. With a mu of 2, the ratio becomes 2/3 or 66%; with a mu of 100, the ratio becomes 102/202 or 50.5%, which means that the two spilt-output-reference variations are probably not the best topologies to use where output impedance is of prime importance. (Actually, the full cathode follower degeneration can be restored by intertwining the driver stage with the output stage, but at the cost of increased driver stage voltage swing: nothing can be had for free; alas.)

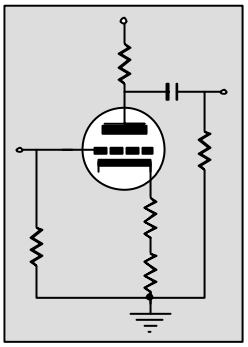
Of course, where Zo isn't important, the equal drive signal amplitudes are truly a blessing, as the unbalanced drive voltages confused the hell of out most tube practitioners and even the makers of Stereophile -Class-A amplifiers and patent examiners. And both center-referenced amplifiers take less driver-stage voltage swing to bring them to full output than the four other variations on this same theme (a result of placing the reference at the midpoint of the output signal; imagine a gain of 100% and this will be more readily apprehended).

How true are these formulas to reality? I don't know, as I don't have examples of the two amplifiers to test, but I know that it is accurate regarding my own pair of Atma-Sphere M-60s. **(What! He owns those amplifiers! I heard he owns an oscilloscope and a distortion analyzer and a FFT, which means that he can test them and evaluate them at his leisure! The horror!)**





I do know that it is true to SPICE reality, in that the two variations produces output impedances of 40 and 60 ohms, a ratio of 40/60 (2/3) or 66%. (What I am not too sure of is the SPICE model of the 6080, as I don't believe the tube is that good in that I don't believe the rp is as low as the model implies, but that little matters to the results so far obtained, as a different tube could be used, say a 6C33 or EL509 or, even, 12B4.)



Bold new topology?

By the way, different part values or different part brands or different part technologies do not make a new topology, no more than a flair for interior decoration makes someone an architect.

At least once a month, I receive an email with schematic of a grounded-cathode amplifier, with a request for my viewpoint on the circuit. The last one I received used two resistors in series in place of a single cathode resistor. My take was that two plate resistors would be a better idea, because of resistor voltage induced distortion.

But the actual point of interest was the choice made to use Radio Shack carbon-film resistors; surely, that was something new and bold.

Topology can exist without parts, just as geometry can exist without stone or wood or steel or plastic objects. For example, prior to the transistor actually being created, a schematic could have been drawn, and most certainly was drawn, that displayed valid topologies that used a part that hadn't yet existed. If you wish for a more abstract analogy, think sentence structure: "Man bites dog" is *structurally* no different than "Man bites cat," no matter what the dog and cat think. Grammar tells us what is possible; rhetoric, what is desirable and effective. Basic electronic theory tells us what can be built that will work; electronic design practice, what to expect in terms of sonics, reliability, efficiency. And while marketing can accurately tell us what will sell, (basically, what we want to believe) only a fool would try to glean basic electronic theory from ads in glossy magazines.

Cars and Planes

Returning to the analogy of the airplane and a car, imagine that your neighbor returns from England with — as he was happy to tell you in a postcard he sent ahead — "an airplane." Soon after he returns, he drags you over to his house and opens his garage to reveal…(a suspense building pause here)...a car. Yes, a Honda Accord, just like yours: same year, color, wheels and tires, sunroof and trim.

You're confused and ask where the plane is. He replies, "you're looking at it; isn't she a beauty?" He insists it's a airplane and will not be persuaded otherwise. You ask him for the specs on his "airplane": engine displacement, number of cylinders, miles per gallon, top speed, 0-to-60 time, braking distance and turn radius — and every answer he gives matches exactly your car next door.

Finally you ask him why he thinks his car is an airplane. His answer is that it said so in the brochure and the salesman assured him it was...besides the personalized license plate reads "Not A Car."

When asked if he has ever flown this airplane, he smugly replies, "Sure, lots of times." But when asked what altitudes he has attained, he says that he doesn't really know; and besides his airplane cannot be tested by normal means, as it is a *very special design;* so much so that the normal measurement techniques, such as hanging a measuring tape outside the window, just don't work; the salesman was quite adamant about that.

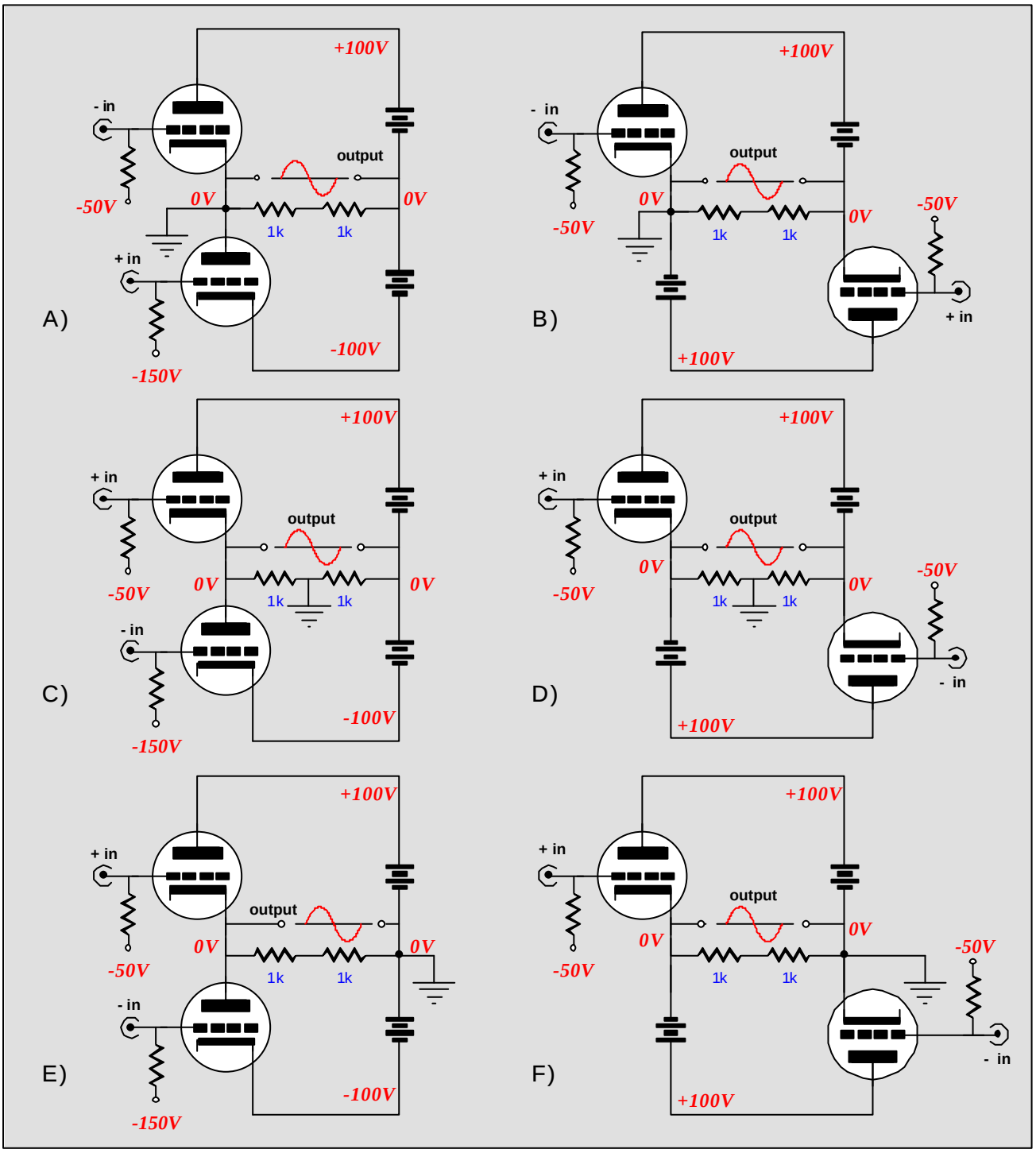
You cannot stomach any more and you drag your neighbor to your garage and show him your Honda Accord. "How is your airplane different from my car?" you plead. He then points out, in a tone usually reserved for small children, that your mere *car* has its steering wheel on the left side, whereas his *airplane* has its steering wheel on the right side. While you stagger from his answer, he says, "Besides, do you really think that I would be stupid enough to pay $70,000 for a Honda Accord?"

Recap

We have seen that we can readily create at least six topological variations out five main components: two large power supply capacitors (each capacitor represents a voltage source, such a single floating power supply or the one half of a floating bipolar power supply), two tubes, and a signal reference. Other topological variations could be had simply by shifting the reference to the top or bottom of each of the circuits shown on the following page, but something has to be left others to invent and patent.

Circuits with their reference at the center of the output, the Ultratron (C) and Circlotron (D), are the most confusing, but they are not physics-defying because of it (advertising copy and internet buzz to the contrary). Which is better? *Better for what?* The circuit with one tube atop the other, the Ultratron (it would teach me a lesson if this joke of a name stuck. So preemptively, I will christen it the "vertical center-referenced push-pull amplifier") offers the advantage of using a single center-tapped power transformer (readily available) per channel. As the power supply the power supply must be left float, two channels cannot share the same power transformer, unless the transformer were decoupled via two center-tapped chokes.

An added plus might be that this topology lends itself more readily to separate idle current and DC offset controls, as one potentiometer would adjust the current through both tubes by varying the bottom triode's conduction and the other potentiometer would adjust the DC offset via the top triode's cathode voltage.



Circuits A, B, Capacitor, D, E, and F all share the same maximum power output, given the same number of triodes and B+ voltages and load resistance, which can be roughly figured out with following formulas:

Imax = B+/(rp + Rload)

Vmax = Imax x Rload

W = (Imax x Vmax)/2

The roughness enters the calculations from the varying plate resistance of the triode, particularly a triode like the 6AS7. (Only the mu, the amplification factor, is fairly constant.) Thus the best plan is to determine the triode's rp on the 0-grid-voltage plate line only, as the previous formulas assume a grid voltage of zero.

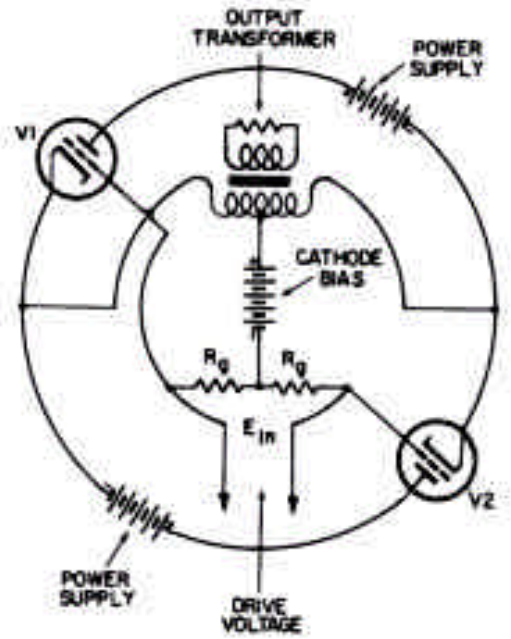
The circuit with the two tubes horizontally arranged, the circlotron (I would love it if we could lose the name "circlotron" and simply call it a "push-pull amplifier" or at most a "horizontal center-referenced push-pull amplifier") offers the advantage of easier output tube biasing, as all the output tubes have their cathodes at same ground potential, allowing a shared negative bias power supply (and heater supply). Another advantage is that the two triodes within a 6AS7/6080 could more readily be wired in anti-phase to each other. In other words, while one is turning off, the other turns on, as was the standard practice not to long ago.

But which is better...you know...*metaphysically?* No, I don't know, nor does anyone else.

Imagine two people arguing who was more powerful, Allah or God? Or which was nastier, the leopard or the panther? Or whether they should plant nutmeg or mace crops next year? In terms of performance, in the absence of any measurable differences, we would have to make *nuanced*, *textured* and *subtle* distinctions, as is in *this one has more drive*, or as in *this one has less drive*. (I am old enough to remember when "share" did not mean to burden someone else with our petty, private grievances, as in "Bob, I have something to share with you;" or when "nuanced" and "textured" and "subtle" might be overheard in a museum or a concert hall, but did not describe hopelessly fuzzy wishful thinking that could never stand up to logical scrutiny, but which is politically correct, so exempt from debate and criticism.)

From a basic electronic theory standpoint, both amplifier topologies are equally valid. From an electronic practice standpoint, the two topologies are too generic, too elemental, too basic, and ultimately, too similar to be evaluated without the rest of the amplifier fleshed out. Which is better positive voltages or negative voltages? Negative or positive power supplies? I don't know, what does the whole circuit look like?

One reader explained to me that the name "circlotron" revealed the true nature of the amplifier, as all the key parts defined one large circle of current flow. He was right, they do; however, all six topologies we have covered here should then share the name "circlotron," as all of them equally complete circles of current flow: remove one part and the current ceases to flow. (But it is hard to imagine a Futterman amplifier being called a circlotron.) In other words, this path leads straight to distinctions based on no differences. (Of course, the marketing department may trump basic electronic theory and electronic practice by declaring that if the public is misinformed or misguided, great let's make some money: sell them whatever they think is better and who cares if there is no difference?)



In Conclusion

We have seen how the "circlotron" amplifier is only one topological variation in a family of similar topologies and that it is functionally identical with the totem-pole variation within that family that places its signal-reference point between the output and "ground." Neither amplifiers are single ended in design, nor necessarily class-A in operation, nor do they defy the laws of physics; they are, in fact, merely generic building blocks that might be used in the designing of a brilliant or mediocre amplifier. With any of the topologies we have covered here, the hard work remains: figuring out how to exploit virtues and diminish liabilities. For each topology a different set of possible schematics exist. Deciding which schematic should be built requires work, weighing positives against negatives. Those looking for free rides will have to look elsewhere.

So will this be the last article on the "circlotron" amplifier? I doubt it, as I can imagine covering the many possible ways to configure the driver stage. For example, on page 7, two schematics were presented to illustrate how the vertical center-referenced push-pull amplifier could be attached to a phase splitter stage in a way that ensured a good PSRR figure, conforming to the Tube CAD Journal's Audio Aikido set of techniques that use power supply noise to lower power supply noise at the output. Many more arrangements are possible.

(For a detailed explanation of how the modern "circlotron" works, click here to download a PDF of what I have found to be the best textbook explanation of the horizontal push-pull amplifier in a grounded-cathode configuration.)

//JRB