Ultrapath, Parallel Feed and Western Electric

By Lynn Olson

In the last two years, independent developments in the Single-Ended Triode (SET) movement have revealed a better way to design vacuum-tube amplifiers. Although it appears at first glance that they only apply to certain SET amplifiers, there is a common thread that ties all of them together. By analyzing the complete AC signal path from plate to cathode, existing circuits can be examined in a different light, and new circuits created, both Single-Ended (SE) and Push-Pull (PP).

All of the combinations - conventional, Ultrapath, Parallel-Feed, Western Electric (WE), and others - are shown in a "Periodic Table of Topologies." The table shows simplified versions of each circuit, which can be preamplifiers, line amplifiers, drivers, or output stages.

Conventional Single-Ended (A)

As Jack Elliano explained in his VTV #10 (pp.11-12) Ultrapath article, a triode is simply a voltage-controlled resistor. To be more exact, the potential difference between the cathode and the grid controls the dynamic resistance of the plate-cathode circuit. When a steady DC current is impressed on the plate-cathode circuit, the tube simulates an AC generator connected to the primary of the transformer. Note the "ends" of the virtual AC generator are the plate and the cathode, not the plate and ground. For that matter, a ground reference is simply a matter of convenience in circuit design, a common low-impedance point that can be shared, but is not necessary for the operation of the tube.

When the tube is amplifying an audio signal, the AC current flows along the dotted lines in the table. It passes through two capacitors, and in typical circuits, these are low-quality polar electrolytics, and not even of the same type or value. If the cathode capacitor is omitted, the dynamic resistance (Rp) of the tube will probably rise three times or more, with disastrous consequences for the bandwidth of the transformer. If the B+ filter cap is omitted, the power supply will become much noisier, and more seriously, the impedance seen by the primary will become extremely high, since the Rp of the tube and the main power supply B+ choke then become series-connected.

Western Electric 86B Push-Pull 300B Amplifier

Both cathode bypass and B+ filter caps are essential for correct operation in a conventional transformer-coupled SE circuit. I don't need to emphasize in this magazine the disastrous impact of low-quality electrolytics on the audio signal, yet as can be seen from the analysis of the AC signal, the electrolytics used in most designs are directly in the audio path.

The best that can be done with a conventional SE circuit is specify better-quality, non-polar caps, such as traditional oil-filled caps, and use fixed bias.

Ultrapath (B)

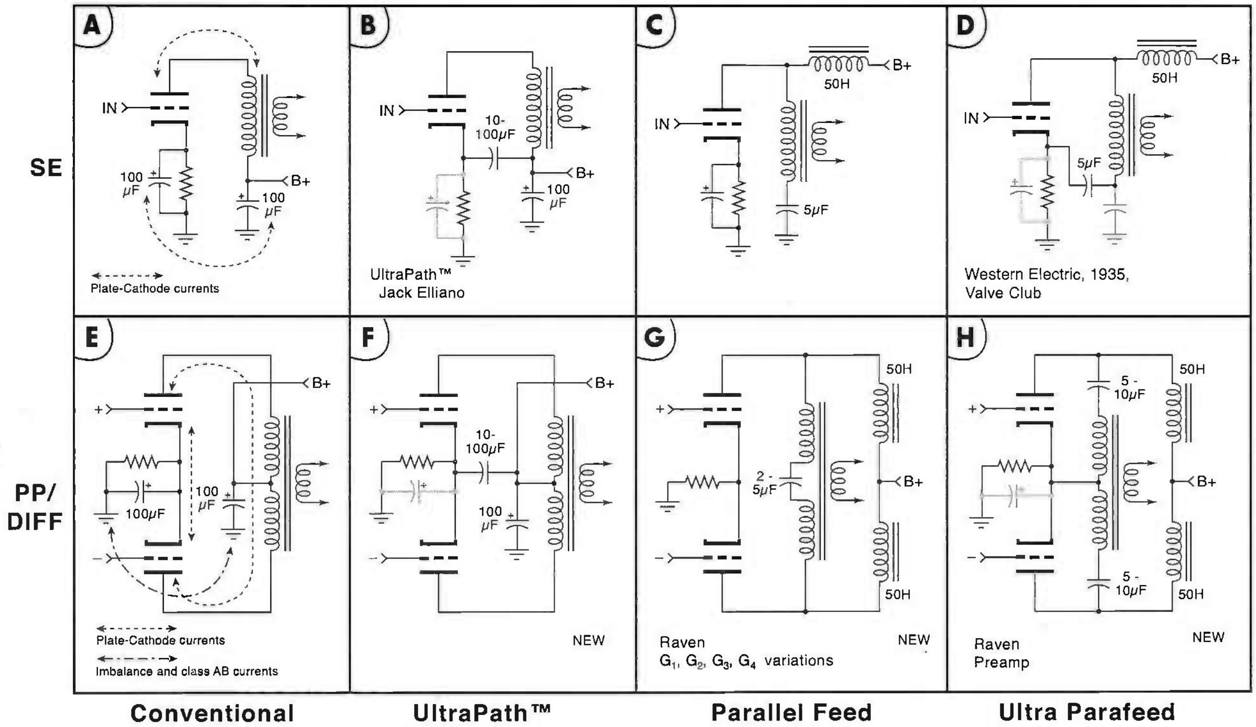
Jack Elliano's Ultrapath circuit solves the problem in a remarkably simple and elegant way; replace the cathode-bypass electrolytic with a high-quality oil cap, and move the grounded end of the cap to the B+ side of the output transformer. That's it. That one change alters the entire operation of the circuit.

With a cathode-transformer (KT) bypass cap in place, the AC generator that the tube represents has a direct terminal-to-terminal path, from plate, to transformer, back to the cathode again, courtesy of the KT bypass capacitor. There is no need for the AC signal to traverse two back-to-back electrolytics. Instead of completing the AC circuit, all the B+ filter cap does is shunt noise away from the audio circuit, a much less demanding application. At a single stroke, the strong colorations of the power supply components are greatly reduced, since the AC signal no longer requires the power supply to complete the AC circuit. All the power supply does is supply polarizing DC so the tube can operate.

The original VTV circuit recommends a 25µF oil cap for a 6J5 or 1/2 6SN7 triode. Since the required value of the new cathode-transformer (KT) bypass is a function of the dynamic impedance (Rp) of the tube and the cathode resistor, larger values will be required for lower-impedance tubes. For example, in a power amplifier with a 300B output, a 100µF oil cap would be desirable. Readers with access to circuit-modeling programs like SPICE can work out the optimum values for their favorite tubes.

In VTV #10, the B+ supply is shown with a conven-

PERIODIC TABLE OF TOPOLOGIES



tional 100µF electrolytic filter cap. Curious experimenters can replace this with an oil cap, and notice how small a difference this makes to the sound. By contrast, if the amplifier reverts to a traditional SE circuit, the difference between the two types of filter cap is far more audible, since the signal from the virtual AC generator is forced to traverse two back-to-back electrolytics. What about regulated-power-supply enthusiasts, the folks who are using old Kepco lab supplies or the modern Allen Wright SuperReg? Does all of this apply to you?

Yes. Remember, in a conventional SE circuit, the power supply is in the direct path of the audio signal. See any electrolytics in there? That's what you're hearing. See any feedback in the regulator? That's there too. Why go to the trouble of building a non-feedback triode circuit if the sonics of feedback are still in the audio path? With the Ultrapath circuit, you can keep the tight regulation, low noise, and ultra-low source impedance of regulated supplies, without the added complications of "tuning" the regulated supply for optimum sonics.

It might seem counterintuitive, but the Ultrapath circuit makes regulated supplies more attractive, not less, since the unpleasant business of tuning a complex power-supply for pleasing sonics is sidestepped. The people who have tried regulated supplies, and gave them up in desperation over the tuning problem, can look at them again with the Ultrapath circuit. I'm making a guess here, but an Ultrapath circuit combined with a regulated supply could offer the sonics of the most exotic all-battery tube amplifier. (Note: "Ultrapath" is protected by trademark laws. Copying an image of the schematic from VTV is prohibited by trademark laws.)

Parallel Feed (C)

In the earliest days of radio, engineers had a choice of transformer, parallel-feed, and resistor-capacitor (RC) coupling between low-mu triode stages (no other tubes existed). B+ power came from unsightly, leak-prone, and heavy batteries that required frequent recharging. B+ voltage was a precious commodity, not something to be lightly burned off in a resistor, and the simple triodes needed every bit of gain available. The first choice was transformer coupling, which maximized efficiency.

When PP amplifiers first appeared, designers realized they could improve the performance of the interstage transformer (which is hard to design because of high impedances on primary and secondary) by isolating DC from the primary. This reduces the size of the transformer core, raises the inductance, and improves high-frequency response (as a result of smaller winding area). When B+ voltage was at a premium, plate chokes were used, and when there was plenty available, a plate resistor. Both variations came to be known as parallel-feed, since the AC and DC follow different paths in the circuit.

In the 1930s, RC coupling came into its own with AC-powered radios and high-powered sound systems in theaters. The extended HF bandwidth paved the way for feedback, vacuum-tube phase splitters, and the various Williamson derivatives that still dominate mainstream vacuum-tube audio. Over the last half-century, device linearity became gradually less important, with high-feedback opamps being the endstage development. With the

Directly Heated Triode (DHT) revival of the last decade, intrinsic linearity has returned to the forefront, and circuits that optimize the performance of zero-feedback triodes are being retrieved from the archives of audio. With encouragement from Michael LeFevre (MagneQuest) and Dan Schmalle (Doc Bottlehead of VALVE magazine), parallel-feed SET amplifiers are creating a buzz in the Northwest part of the USA. (Niyom Nakarin of Fi-Sonik and John Atwood of One Electron are also fans of parallel feed. -ed.)

On paper, parallel-feed is an ugly business, seeming to add an unnecessary cap and plate choke (or current source) to what would otherwise be a conventional SE circuit. Calculating the value of the coupling cap feels a little odd as well. Using the formula for resonance, set f between 6 and 15Hz, so f = 1/(2*pi*sqrt(LC)), with C being the coupling cap and L the primary inductance of the transformer. In practice, the coupling cap is considerably smaller than the usual cathode-bypass, with 1 to 6µF being typical.

(If you make the cap larger than optimum, it creates a subsonic peak, which muddies the bass and can damage the woofer. People who want to go beyond the crudity of cut, try, and listen are invited to model parallel-feed on SPICE.)

What does parallel-feed sound like? Contrary to expectation, the bass region sounds very similar to regular SE, but from 500Hz on up, the sound is noticeably more direct and open, with a significant subjective extension of HF response. This is not what you'd expect by glancing at the schematic; like SE itself, what you actually hear is quite different than the initial pre-conception of what you expect to hear.

What accounts for the change in the mids and highs? For one thing, power-supply colorations are nearly totally isolated from the audio circuit by the plate choke; at mid-frequencies, the power supply resembles a current source, not the usual voltage source, with a very significant amount of isolation between the B+ filter cap and the audio circuit. This is not a trivial matter; power supply colorations can easily overshadow the choice of tube or any other part in the audio path of the circuit. In most amplifiers, just swapping parts in the power supply is the most effective "tone control" in the entire hi-fi system ... certainly more effective than playing with interconnect cables.

Secondly, nickel or mu-metal transformer cores are a different animal than the usual air-gapped M6 silicon-steel transformer core. Nickel cores have essentially no tolerance for DC at all, plus they saturate hard and fast ... but offer superb low-level performance, especially in the midband. There's a reason that nickel cores are used in microphone transformers, professional applications that demand the last word in low-distortion performance.

There are several ways to get parallel-feed wrong: one is to cheap out and use power-supply chokes for the plate choke. Power-supply chokes are not designed for this application, and can have a self-resonance as low as several kHz due to stray capacitance. Plate chokes, by contrast, have self-resonances as high as 70 kHz due to better control of stray capacitance, and pay more attention to the choice of dielectrics used in the construction of the inductor. Another way to get parallel-feed wrong is to use an off-the-shelf SE or PP transformer; since the circuit offers the prospect of near-zero DC flux across the output transformer, why not take advantage of the best-available core material for the operating condition?

The VALVE group in Seattle have discovered that oil caps, which can sound "slow" in other parts of the circuit, do not sound that way at all when placed in a parallel-feed circuit. Their experience with film caps is that they sound even more colored in parallel-feed, so oil is the way to go. The same cap-selection considerations that apply to Ultrapath apply to parallel-feed, with the difference that the parallel-feed cap is likely to have an optimum value somewhere between 1 and 6µF.

Western Electric SE (D)

Although this circuit appears new, it is actually very old. Take a close look at the single-ended 262A driver in the schematic of the Western Electric 92B amplifier. C1-C connects the 262A cathode to the low-side of the interstage driver transformer, forming a an audio-frequency shunt between B+ and the cathode (BK). The cathode-transformer bypass isolates DC from the interstage transformer (improving bandwidth and power-handling), and the plate current for the 262A is supplied through a 100K power resistor. It can be seen that the 100K resistor can be replaced with a plate choke or current source with no significant difference to the operation of the driver stage. As with parallel-feed, it is best to keep the cathode-transformer bypass to a moderate value between 1 and 6µF.

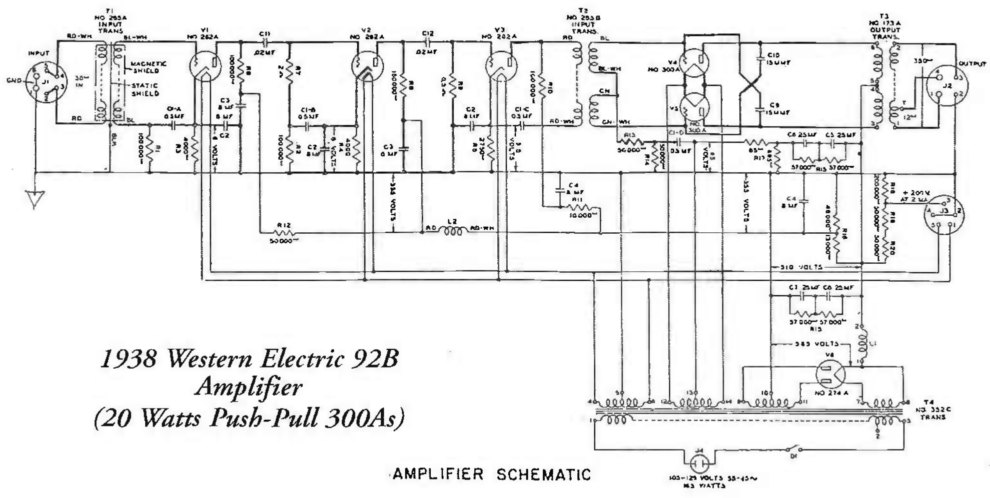
The WE SE circuit combines features of Jack Elliano's Ultrapath and parallel-feed; however, the ghost of positive feedback lurks nearby, ready to make trouble. The Ultrapath circuit has the B+ filter cap shunting the low-side of the transformer primary to ground; no such shunt exists in the WE SE circuit. As a result, a small signal that appears at the plate can be re-amplified at the cathode.

In practice, the load of the transformer acts as a voltage divider for the cathode resistor, so the extra gain is only significant at low frequencies, when the effective transformer load falls to the DC resistance of the primary. Another way to analyze the positive-feedback potential of the circuit is to turn it on its side, and make it a grounded-grid amplifier with (positive) feedback from plate to cathode. It can be seen that the voltage-divider action of (transformer + KT bypass) / (cathode resistor) in the feedback path is the only thing preventing this circuit from entering full-blown oscillation.

A simple way to shut off the positive-feedback effect is to re-introduce the cathode-bypass capacitor, using a much larger value than the KT bypass (such as 100µF). This greatly increases the effectiveness of the voltage-divider, stabilizing the circuit at all frequencies. Note that Western Electric didn't do this, using a very modest 0.1µF for the cathode-bypass (C2). The WE engineers probably selected the values of C1-C and C2 to trim the LF response of the interstage transformer (T2).

Audibility of Power Supplies

The typical way of thinking of power supplies in terms of hum and noise is grossly oversimplified. With conventional triode, pentode, or transistor circuits, the power supply is directly in the audio path, and the audio signal is fully exposed to the low-quality parts used in power supplies.



1938 Western Electric 92B Amplifier (20 Watts Push-Pull 300As)

In transistor circuits, the problem is aggravated by the low operating impedances, which in turn require very large bypass capacitors. Unfortunately, the only caps you can buy in 1000µF and larger values are electrolytics, which are so nonlinear that loudspeaker designers go to great lengths to avoid them, even in subwoofer applications. In a transistor amplifier (or preamp), the large-value electrolytic isn't just in the low-frequency part of the circuit (as it would be in a speaker), but exposed to the full bandwidth of the audio path. Take a good look at any "direct-coupled" transistor circuit and count up all the bypass caps you see; unless the circuit uses the techniques of Ultrapath, parallel-feed, or Western Electric, these caps are directly in the audio path. Paralleling the low-quality electrolytics with film capacitors may improve high-frequency response, but it does nothing for the underlying nonlinearity of the much larger electrolytic.

The typical values of feedback used in transistor circuits may linearize the transistors (which need it), but feedback can't make much of a dent on the time-dispersion problems (Dielectric Absorption) of electrolytic capacitors. In fact, feedback may worsen the defects of electrolytics, spreading out the time-dispersion even more and adding high-order terms to the underlying nonlinearities. This might be an important reason that simple, high-slew-rate, moderate-power transistor amplifiers are the most "triode-like" of transistor amps; there are fewer electrolytics, they have smaller values, and there's less feedback. The circuit isn't any better; there's just less to go wrong!

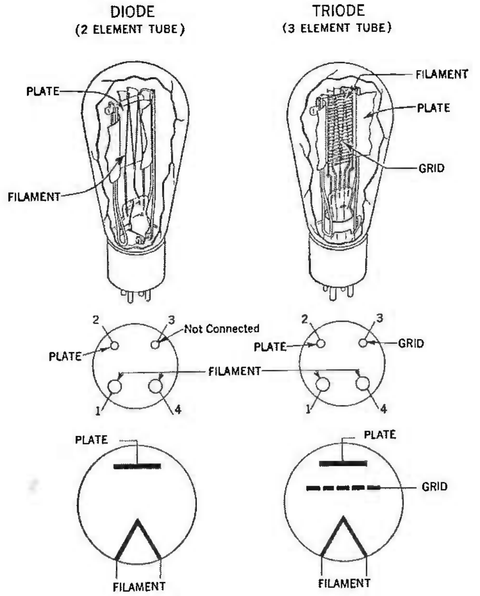
Conventional Push-Pull (E)

Part of the reason I wrote this article is to nudge push-pull enthusiasts away from endless variations of 1950's circuits such as the Williamson, Acro, Dyna, Citation, Marantz, and McIntosh. After strip-mining the "Golden Age" for the last half-century, there's no gold left anymore. The mine is played out.When you compare "Golden Age" designs to the entire span of vacuum-tube audio - more than 80 years - they are pretty similar, with 20+ dB of feedback, RC-coupling, pentodes, and vacuum-tube phase-splitters. This narrow slice of audio history is all that comes to mind when audiophiles, magazine reviewers, and hi-fi dealers think of "Push-Pull." That's all that North Americans and Europeans had ever heard, until the first SE-DHT amplifiers exploded on the scene in the early Nineties.

But you know what? A zero-feedback, non-RC-coupled, all-triode amplifier sounds as different from conventional PP as conventional PP sounds from single-ended direct-heated triode! It's a sound that will take most audiophiles by surprise once they hear it ... yet in engineering terms, it's nothing more complicated than selecting the most linear electronic devices (direct-heated triodes) and topology (very deep Class A push-pull). When the adventurous designer enters the new/old territory of naturally linear circuits, there are some things to watch out for. For one thing, power supply coloration becomes more objectionable, not less, when it can't hide behind a veil of distortion. The conventional wisdom says that Push-Pull, or differential, circuits are less sensitive to power supplies as a result of Common-Mode Rejection (CMR), which expressed another way, results in an improved Power Supply Rejection Ratio (PSRR). This is only true in the gross sense of hum and noise, which are easy to measure, and is the end of the story for conventional wisdom.

What about sonics? Conventional single-ended circuits are fully exposed to power supply colorations, as shown in the previous part of the article. If-and only if-the PP circuit were perfectly balanced at all frequencies and power levels, it would have near-total immunity to power supply coloration, in addition to the expected hum and noise rejection. All of the AC current would flow from tube to tube, plate to transformer to plate to cathode to cathode, ending right back where we started. A beautiful picture of symmetry, all of the AC current flowing in a circle, needing no reference to ground either through the cathode-bypass cap or the PS filter cap.

In the world we live in this Platonic ideal of balance is never attained. In practice, the best that can be hoped for is about 5%, and we have to go to considerable lengths to make sure there are no frequency, level, or power-supply variations in the balance condition. The PP amplifier has a poor-quality SE circuit hidden within it, with the disagree



able property of unpredictable gain. If the PP circuit has typical phase-splitters (split-load, long-tail, see-saw, etc.), there's a frequency and level dependency to the SE circuit's gain. The drift in the balance condition is usually swept under the rug with the remark that if it's hard to measure, it can't be very important.

The poor-quality SE amplifier hiding within the PP circuit is just as sensitive to power-supply coloration as the SE circuits in the previous section, with the added problem of selective amplification of power-supply coloration. In other words, with a physical SE amplifier, what you hear is what you get. If there's an electrolytic cap in the B+ filter circuit, it sounds like an electrolytic in the signal path. With the SE circuit hidden within the PP amplifier, there's the added problem of unstable gain to factor in. The electrolytic in the B+ filter circuit is audible, but it is behind a shimmering, gain-unstable circuit. This may be worse than the true SE circuit; the magnitude of audibility may be 26dB lower, but what's left is bouncing around with the signal, introducing a brand-new coloration that wasn't there in the SE circuit.

So in practice, PP circuits have less hum and noise than SE, but they also have power-supply colorations that are in some ways worse than a SE circuit. This may be why SE circuits are easier to "tune" than PP; the audio signal that is impressed on the power supply of a PP amplifier is considerably "dirtier" than a SE amp, where it is simply a clean and direct copy of the audio signal. If there is any tendency for the PP circuit drift into Class AB, the audio signal impressed on the power supply gets even dirtier, with substantial amounts of distortion present. The criticism of "haze" and unmusicality for PP amplifiers can be laid directly at the door of a complex and unstable power-supply coloration that is difficult to "tune out" in the manner of SE amplifiers.

Western Electric PP (F)

The KT bypass of this circuit provides a low-resistance, low-distortion path for the SE residue of PP. With the addition of one bypass cap, the 100µF B+ filter cap is no more than a noise sink, and is no longer part of the audio path. This circuit has the charm of simplicity, and cathode-bias PP amps can easily be converted to WE PP - just be sure to use high-quality oil caps for the KT bypass, not poor-quality electrolytic caps, or you'll be right back where you started. Although it is desirable to keep the B+ filter cap to the existing large value, the bypass can be reduced to a fraction of the filter-cap value, which helps reduce the cost of the oil cap.

The WE PP circuit has special merit for PP applications where any possibility of Class AB operation can occur, since the brief excursions into the Class-B region require a low-impedance path between the plates and cathodes of the power tubes. If the low-impedance path flows through electrolytics (as it does in many PP amplifiers), the electrolytic coloration will suddenly intrude whenever one tube cuts off. This will only magnify the subjective colorations of the AB transition, which is already a problem for the amplifier designer. The WE PP conversion at least gets the amplifier closer to the "textbook" condition that assumes perfect capacitors with zero coloration.

Where does this circuit come from? Take a close look at bias circuit of the PP 300A's in the Western Electric 86, and in particular, C5 and C6. Although we have no "Theory of Operation" for the WE 86, the function of C5 and C6 are clear; they are KT bypass caps, similar to the C1-C bypass caps in the 262A driver section of the amplifier. (The function of C1-D and R13, R14, and R17 are less clear, and might be part of a hum and/or 3rd-harmonic reduction circuit. SPICE experts are invited to model this part of the WE 86 and let us know what they find.)

The WE 86 is old. The 300A specification tells us that the WE 86 schematic was drawn no later than 1935, when the 300B replaced the 300A. Just think, FDR was in the first term of his presidency when the WE 86 replaced the first-generation 211 amplifiers in movie theatres. There are fascinating design features in the WE 86 that were forgotten by the time of the Williamson, never mind the present.

Parafeed PP (G)

This is an interesting variation of parallel-feed for PP, and takes advantage of a split-primary transformer so that only one cap is necessary for the DC-blocking function. It might seem unnecessary to block DC - after all, PP transformers are designed to accommodate a moderate amount of DC - but zero DC allows core materials that would normally be off-limits for a PP transformer. The small amount of imbalance current might seem a minor matter, but it's not.

In the course of designing the Raven line-stage preamplifier, I collaborated with Brian Sowter of Sowter Transformers. The Sowter 9111 line-driver transformer has a 50% mu-metal core, and my original plan was to use a 10-turn balance pot to trim the DC balance of the circuit. Then Brian sent me the results of a test he had done on a production transformer that had the same core (and similar windings) as the new 9111.

Brian put a 20V 50 Hz sinewave on the primary, and measured the output distortion of the transformer for different amounts of DC offset. Here are his results:

Offset (mA)	THD+N (%)
0.0	0.0109
0.05	0.03
0.125	0.06
0.25	0.119
0.5	0.162
1.0	0.219
1.5	0.332
2.0	0.219
2.5	0.633

These are sobering numbers as only 50 microamps raises the distortion nearly threefold. A more typical 5% imbalance (1 part in 20) gives a twenty-fold increase in distortion! The transformer distortion null is razor-thin maybe 10 microamps wide. Think of it: for a preamp that runs at 20 mA per side, 10 microamps of DC offset is one part in 2000. That's a lot to ask a 10-turn trimpot: you might be able to adjust it to that precision, but how long will it stay in adjustment? Half an hour? As a former Tek employee, I know that DC precision and vacuum tubes are two things that don't go together.

The most direct solution is parallel-feed. Nothing to adjust, ever, and the series resistance of the plate chokes helps keep the tubes in DC balance-not that it matters to the output transformer, which only sees the infinitesimal leakage current of the capacitor. As with SE parallel-feed, the matched plate chokes buffer the power-supply coloration (and noise) from the audio circuit, but with an additional 20 to 30dB of noise rejection. If you want silence and a wide dynamic range, this is the way to go.

KT Parafeed (H)

This circuit is really blue-sky; whether it is "better" than the two previous circuits is hard to say. As mentioned before with the SE version, you might encounter positive-feedback operating regions, so a large cathode-bypass cap is probably desirable. As with SE, the cathode-bypass cap doesn't really do anything, it just shunts positive-feedback voltages to ground.

In terms of how the circuit operates, the two sides are in parallel, in comparison to (G), where the two sides are in series. How do you check? Easy. What happens when one tube is removed? With (E), (F), and (H), the circuit reverts to SE, which is another way of saying they are capable of Class AB operation (depending on load and bias). With circuit (G), both tubes are in series, so removing one tube shuts down the circuit; this circuit can only operate in Class A.

Conclusion

Conventional SE and PP circuits are directly exposed to the sonics of the parts in the power supply, with transistor circuits having the greatest problems as a result of low impedances and the consequent requirement for large-value electrolytics.

Jack Elliano's Ultrapath, parallel-feed, and the Western Electric circuits take advantage of a transformer's floating primary and make it part of a filter to isolate the power supply from the audio circuit. The isolation techniques can be applied to any transformer-coupled circuit, single-ended or push-pull. All benefit substantially from added power-supply isolation, not just in terms of easily-measured hum and noise, but in more audible but harder-to-measure subjective qualities.

By partitioning the audio and DC portions of the circuit into two separate elements, each can be optimized for the task it has to do--linearity for the audio portion, and isolation for the power supply. At first glance, they may look more complex on the schematic, but these circuits takes better advantage of the non-ideal properties of capacitors, inductors, and transformers.

This article only skims the surface of a new territory of vacuum-tube amplifier design. I am not a mathematician, so I hope those who are better qualified will jump in, analyze the new circuits, and share their discoveries with the readership of VTV. As for fearless experimenters, gentlemen, you may start your engines!

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Lynn Olson has written for the Audio Engineering Society Journal, Positive Feedback, Glass Audio, and was the editor of Valve & Tube News during its span of publication. He is a co-founder of Aloha Audio, and is the webmaster of the Ariel Speaker Page at: http://www.teleport.com/~lynno/Ariel.htm
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