The Missing Sonic Controls

Imagine if you encountered a telescope manufacturer, whose product line embodied a severe minimalism: telescopes built with the fewest lenses possible, telescopes without eye adjustment knobs, telescopes without color or polarizing filters, telescopes without magnification adjustments, telescopes that were instead built to a single fixed magnification and fixed position, telescopes that could reveal only a few celestial objects in clear focus because of the fanatical adherence to preserving the all of the purity of the light entering the telescope; and if you complained about the blurry image of your favorite star, the manufacturer would superciliously reply that your favorite star was not worthy of his telescopes and that you should be looking at other, better stars — if you encountered such a strange business, then you would not see anything that radically different from what is practiced in high-end audio today.

In high-end audio, it is human beings who were created for audio equipment and it is they who must conform to its demands. Thus, balance controls are rare; tone controls, nonexistent; so too, stereo/mono switches and, heaven forbid, equalizers or loudness controls. It is as if the Puritans' renunciation of shiny buttons has been one-upped by the elimination of buttons altogether.

In a high-end salon, played on a $40k system, a system made up of some of technology's newest triumphs, most of your once-favorite albums, strangely enough, no longer sound good. And while a few high-quality recordings of mediocre performances do sound good, they do not artistically merit a second listening, an amazing technological feet, considering that your favorite music was once enjoyed readily when heard through a car or table radio's single 5-inch speaker.

What would it take to enjoy once again your favorite music? More money? Greater technological advancements in the design of CDs, amplifiers, and loudspeakers? Still the 5-inch loudspeaker once did provide enjoyment while playing certain songs. No, the restoration of that lost enjoyment requires not more money nor even better technology, but a restoration of lost sonic control over our listening system, as only by doing so can we regain the ability to tailor and adjust the sound, to undo the stark minimalism, to exploit the technologically advanced stereo equipment available today, to adapt to the music we want to hear; in other words, to make the system conform to our demands, our pleasure, and our enjoyment.

But...wait a minute! What does our enjoyment have to do with sonic truth? Shouldn't a stereo system be like a perfectly clean window giving unto the Kingdom of Sound? Thus, do we not all seek the absolutely *true* sound possible, wrinkles and warts included? Far too many of us do, unfortunately. Consequently, the prevailing view today is that a stereo system should be something like an entirely objective reporter, reporting the facts, just the facts. Thus, the case of the missing sonic controls does not appear in a modern mystery novel, because we all know who did it: we all did it. When we wanted sonic controls, manufacturers sold us controls; and when we eagerly sacrificed sonic controls at the altar of purity, the same manufacturers stop selling them. In other words, sonic control was forsaken in the quest for the "absolutes."

What are these absolutes? It is as if the philosophy's old war between Realism and Idealism has been fought again between the meter readers and the golden eared and the war has ended in a truce that prohibits either side from using sonic controls. For the scientifically inclined, the absolute is the electrons themselves. As long as the scope shows no difference between incoming and outgoing signals, it does not matter how an amplifier sounds in your living room with your loudspeakers. All that matters is the easily specified voltages and currents created by the electrons. Engineering has met its conditions of satisfaction, which do not include your enjoyment. Adding a slight boost at the mid-frequencies would devastate the amplifier's 0.0002% distortion rating.

Conversely, for legalistically or religiously inclined, the absolute is the sound its self. It is the compression and rarefaction of air at some unspecified point in some unspecified concert hall at some unspecified relative humidity, temperature, and altitude. Although unspecified, this absolute is known as much as the Earth is known to be only 6000 years old to the fundamentalist (and since he already know all that is important to know about the Earth, why bother with geology?). And this unspecified-but-known absolute is proclaimed by an exalted few, audio's new prophets. For these earnest few, epistemology easily makes the otherwise-impossible jump into ethics: they proclaim that any deviation from the known-but-unspecified absolute is as morally wrong as telling lies. For these grim few in the know, enjoying the sound from a table radio is no minor sin.

A lesser sin would be turning up the volume on the tweeters to compensate for a failing hearing response at high frequencies. Surely, the nobler stance would be to leave the high frequencies flat, as that is what it sounds like in the concert hall, no matter how unpleasant the music may be at the concert hall for that reason to the man with failing hearing. Verily, if a man wishes to partake of a pure sound, first let him have pure ears. Following this logic, shouldn't all eyeglasses have flat, clear lenses so as not to alter the purity of the light? What does it matter if the near-blind are unhappy?

Remember H. L. Mencken's definition of a Puritan as someone with the haunting fear that someone, somewhere, may be happy. Happy? Why would you want to be happy, when you could be right? But what if happiness was the goal and not absolutes? Stop and think about the consequences: if our sonic enjoyment becomes the object of our efforts in audio design, why then we might just go on to wanting chairs and sofas to be comfortable, not just orthopedically correct; office buildings to be beautiful to behold, not just volumetrically efficient boxes; and food to be delicious, not just nutritious.

We would want to abandon singular and constant absolutes for varied and changing tastes. Supposedly objective experts would have a hard time selling absolute audio magazines, as no one could (at least with a straight face) proclaim the superiority of his own absolutely correct taste. Rock 'n roll, rap, reggae, and modern country music aficionados could no longer be derided justly by those who preferred an acoustically pure music such as jazz and classical. What sonic flavor would make everyone happy? I do not know; which one shoe size would make everyone happy? All must choose their *own* preferences. Without sonic controls, there can be no choosing.

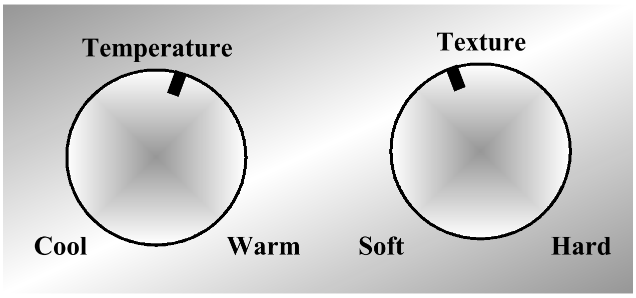
Admittedly, at least in part, the loss of control was justified by the elimination of real and imagined sonic contamination resulting from extra potentiometers, switches, ICs, transistors, tubes, and reactive parts in the signal's path. Certainly, a poorly designed tangle of wire and parts can harm the delicate signal. So no argument is being made for needless and hollow bells and whistles. No, what is needed is sonic controls that are as lovingly designed as a Stradivarius was created. So while part of the loss of sonic can be attributed to poor design choices in the past, part of the equation was also the happy renunciation of responsibility.

I remember hearing one famous designer of men's clothing answer the question "Why does designer clothing sell so well?" with the observation that most consumers had no confidence in their ability to make valid aesthetic choices and the designer label freed them from that responsibility. Think about it: wearing another's aesthetic sensibility is as weird as wearing his old underwear or using his toothbrush. Surely, choices born of our own private aesthetic sensibility should be the easiest to make. And if those choices did not require confidence and did not often result in moral condemnation from ourselves as much as from others, they would be easy to make. By choosing our sonic palette, we must assume the responsibility of those choices.

Since the heroic is no longer unfashionable (as of September, that is) let me tell you of one my heroes.

Back in the 1980s, a friend and I took a wine appreciation class. Our class was small and already well experienced with wine. Our instructor worked at a winery and he thoroughly knew wine, bringing excellent examples, taking great care always to maintain a consistent vocabulary for describing wine, something woefully missing from audio practice.

One day the instructor brought in a brown-bagged bottle of wine and poured us all a glass. We all sipped at once and we all gasped at once. We had just tasted Ripple— or Thunderbird? — or some other wino-favorite given to us as a *reality* test. Some choked and cursed; others immediately spat the wine out; but one us of us swallowed and smiled. He eagerly asked the name of the wine and then said that it was exactly the wine he had wanted to drink all along, but which he could never find. He marveled at the money he had wasted on fifty-dollar bottles of wine. He then stood, collected his things, and permanently left the class with his treasure. He knew what he liked and he did not care what anyone else thought. His heroic act inspires me even today.



Dream Line Stage

So if I could have a dream linestage, besides the usual selector switch and volume control, it would have at least *twelve* sonic controls. Some of the controls already exist, such as phase and balance. But others, such as illumination, dynamics, rhythm, temperature, width, tone, texture, position, and depth, weight, do not exist, but should (we have a lot of work ahead of us). These extra controls would bring the sound from your speaker under your control and your entire music library could be pleasurably played. What then follows is a list of the controls and their functional extreme settings:

Attribute	Extremes	
Illumination:	Dark	Bright
Dynamics:	Compressed	Explosive
Rhythm:	Slow	Fast
Temperature:	Cool	Warm
Width:	Narrow	Wide
Tone:	Thin	Rich
Phase:	Minus	Plus
Balance:	Left	Right
Texture:	Soft	Hard
Position:	Recessed	Close
Depth:	Shallow	Deep
Weight:	Light	Heavy
Height:	Low	High

Wait a minute. Isn't this more like making a musical instrument than engineering a strictly linear electrical circuit? Yes it is, but an analogy from photography and painting might help ease the thought of abandoning the objectively linear. Paint and canvas are not reality, not a woman sitting peacefully, nor a mountain reflecting a morning sun. Thus, for the artist to fool us into seeing reality, he must resort to techniques that overcome the seeing of just blotches of paint on cloth. When photography was invented it was assumed that reality had been perfectly captured. But the captured reality in photos often looked unreal, so photographers found that by borrowing some of the painter's techniques they could make photos "appear" closer to real.

Besides, there never was a pure, unalloyed, unbesmirched, virginal audio signal to begin with. The microphones' physical construction and selected position already grossly altered the sound's capture. And the cabling and preamps and mixers that followed further altered the signal. Then we added the remastering, the processing, and the conversion to playback media (ADC-to-DAC or RIAA equalization to playback inverse equalization) to the signal's aberrant course. What signal integrity that might have survived was finally run through the sound processor known as your system, playback deck, amplification, cabling, speakers, and room acoustics included. There absolutely nothing left of the piano or flute playing in a hall long ago that is untouched by this long chain. Still, some argue that we should regard the record or CD as absolutes in themselves and try to preserve that arbitrary purity from there on.

But why? All CDs and records come sullied, so why should we pretend otherwise? Imagine that you visit a friend's house and while there you watch an old Marilyn Monroe movie. You complain that Marilyn has a decidedly green cast about her. Your friend assures that the picture is correct. "How so?" you ask. His reply is that he has measured the video signal coming out of his cable feed and the green cast is contained in the color burst information of the feed. Your friend adamantly refuses to alter the picture to bring Marilyn's skin back to something closer to human, for to do so would be untrue to the electrons that trace the cable's signal.

Should you call the cable company to complain, they might reply that they have the actual film in their hands and it has a green cast about it due to aging, which they do not wish to correct, as they respect the absolute purity of the film. "Still, a green Marilyn Monroe?" you think to yourself.

Before you think that I am going start arguing for an absolute skin tone, imagine that instead you had found Marilyn's skin a bit too pink and commented so. Your friend's reply is that he purposely adjusted the color so, as he prefers to see her that way. Is he wrong? If so, how can someone's preferences be wrong?

And if so, is he absolutely wrong or relatively wrong? And if his preferences are wrong, is he, indeed, morally wrong for holding them? In fact, do his preferences even have to be logically consistent? For example, I once knew a woman who, when given the choice between cream and half-and-half for her tea, always choose cream; and when given a choice between half-and-half and milk, always choose half-and-half; but when given a choice between cream and milk, she choose milk. Was she wrong? If so, how?

So I am saying that we should abandon all absolutes and logic? No, both absolutes and logic have place, but that place is not where they have been misplaced in audio practice. Consider this: is not the obsession with an imagined absolute sound, ultimately, at its core, philistine --as philistine as the meter-reader's obsession with 0.0003% distortion. For such an obsession with an absolute sound exalts sound over music, although the actual music is not the same as the sound. What? Doesn't sound equal music?

When deaf, Beethoven not only created great music, but he also more profoundly and absolutely experienced that music than those who could hear his music only by sound waves. For sound is really only the usual medium by which the playing of instruments is brought to our ears, but the essential aspect of music is experienced in between our ears, just as poetry is not found in the splattering of ink on paper or electrons flowing through an amplifier or even in the flapping of a loudspeaker's cone.

Thus, a more honest and informed absolute is found not in the *electrons* and the *sound*, but the *music* itself. Thus we should judge a sound not by some imaginarily perfect sound, but by how true it is to the music. Many of the usually disparaging audio attributes, such as "strident, brittle, and glaring," might be perfectly appropriate and *true* to a certain Shostakovich composition, just as "sweet, fluid, and warm" would be equally inappropriate and untrue. In this sense, all un-adjustable stereo systems are like broken watches: only occasionally are they accurate. Like the fixed-magnification telescope of the earlier example, what our systems need is a means of easy adjustment.

(One great advantage the turntable held over the CD player was the turntable's allowing some sonic adjustment. Increase the VTA and the sound becomes more aggressive; loosen the cabling and the sound becomes defuse. The problem here is that the adjustment is not easy.)

Let's be honest: much of the stereo gear and accessories made are no more than un-adjustable tone controls. We choose a certain patch cord that lessens the sizzle from the tweeters. We buy oil-coupling capacitors to undo the harsh artifacts of modern recordings. And there is nothing wrong with these practices other than they are not very flexible, as different songs on the same album often require different sonic antidotes. Changing coupling capacitors per song is too much to ask. Even changing a knob's setting per song is asking too much. (Once a twelve-knob linestage is created, the best addition would be a microprocessor that would keep track of each track and automatically apply the last used settings for that track.)

Making the Sonic Controls Work

Each sonic control requires making some change to the circuit. It might be as little as increasing or decreasing the idle current. Or it might be as complex as switching types of tubes or even circuit topologies. Switching between different coupling capacitors and plate resistors might be needed. Varying the amount of feedback while co-varying the input signal might also be useful in certain sonic controls. The hard part is correlating the desired sonic signature with some aspect of the circuit that can be switched in and out of the circuit. Only a few of the controls can be presently implemented, as our ignorance of the psychoacoustics behind the perceived sonics and electronic circuits is depressingly vast.

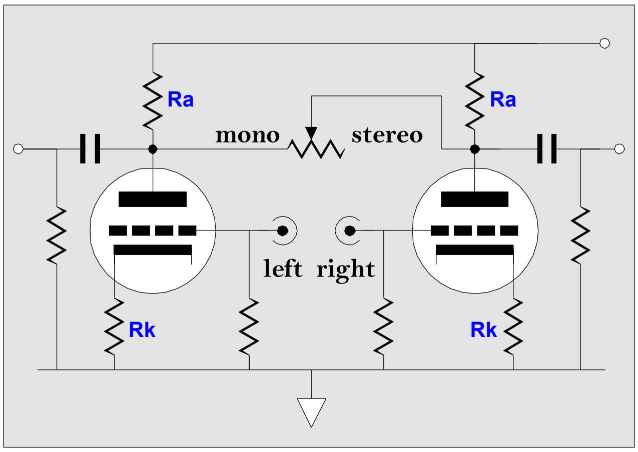
Width Control: Narrow and Wide

Combing the left and the right audio signals into one narrows the sonic stage width by creating a mono signal. Interestingly, the result seldom sounds like a single loudspeaker being fed a mono signal, as the image always seems wider and less spatially specified. Why? Some of the blame must lie in the disparity between loudspeakers, differences in frequency response, mismatching in crossover components, and different room reflections. And certainly some of the blame must lie in the disparity between linestage and power amplifier channels.

Expanding the width requires cross feeding an inverted phase signal from the opposing channel (ultimately, this signal should be frequency selective). A 100% ratio will completely eliminate the signal common to both channels, resulting in a extreme separation of instruments, so extreme that some instruments will appear far to the outside of the speakers.

A reasonable amount of constriction and expansion might at the 50% mark for both adding and subtracting one channel from the other. How do implement such a control?

Starting with the blending into mono direction, the plan is simple: place a varying amount of resistance between the plates of two grounded-cathode amplifiers. The smaller the resistance, the greater the blend. Hitting the 50% mark requires that the bleed resistor equal the rp in parallel with the plate resistor in a grounded-cathode amplifier with a bypassed cathode resistor.

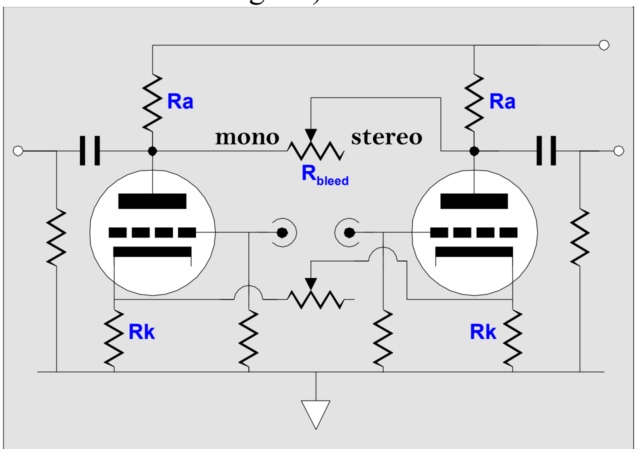


But the cathode resistor should be left unbypassed, as an unconstrained cathode will be needed to implement the broadening of the signal. With the unbypassed cathode resistor, the resistor value for 50% must equal:

$$R_{Bleed} = R_a \,||\, [r_p + (mu + 1)R_k]$$

This value ensures that whatever signal is present in one channel will be reduced by half in the other channel. For example, if the mu equals 20, the rp equals 8k, the cathode resistor equals 1k, and the plate resistor equals 20k, then the bleed resistor must equal 11830 ohms.

We can expand the sonic width by cross feeding an inverted phase signal from the opposing channel. Injecting one channel's signal into the other channel's cathode will cause the injected signal to be amplified at the plate, but in anti-phase. (Actually, the phase of the injected signal is preserved, but as the grounded-cathode amplifier inverts the signal at its grid, effectively the injected signal is inverted relative to that channel's normal signal.)



Achieving the 50% mark requires that the difference resistor's value be set to permit one channel's output signal to be reduced by half at the opposing channel's plate. Cross feeding 50% of the input signal to the opposing cathode would yield more than 50% at the plate, as the input signal at the grid is being effectively reduced by the cathode degeneration. But as the cathode resistor only sees a fraction of the input signal, cross feeding the whole of this cathode resistor signal will probably not yield us the desired 50% mark.

(The cross-coupled phase splitter might be the best circuit to work with, as it might allow a greater amount of control.) Thus, the value of difference resistor one extreme is arbitrarily given by:

$$R_{Dif} = 0$$

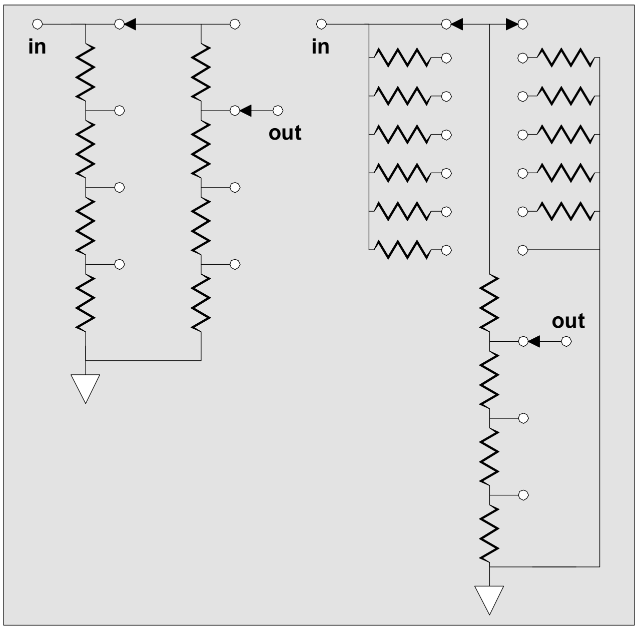
and at the other extreme:

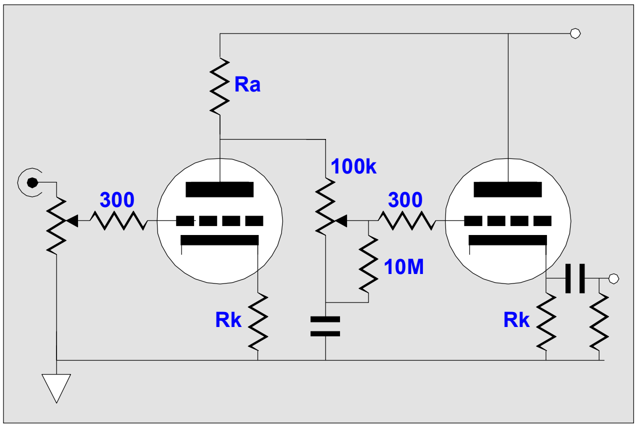
$$R_{Dif} = muR_k$$

Ideally, potentiometers would not be used, being replaced by rotary switches, which would allow for 0 and infinity to be the extremes. The use of rotary switches would also allow the mid-position (neither narrowing or broadening) to be realized easily, something that would be difficult with potentiometers.

Balance Control: Left and Right

Extreme range of control is not the object here. The assumption is that the balance is already fairly close and that all that is needed is a fine adjustment; say a total of 3 dB of range in half a dB increments. Several possible topologies present themselves. We can cascade two series or ladder or combination of attenuators, one fine and one coarse. Or we could place an adjustable resistance in series with the normal volume attenuators. Or finally, we could place the balance attenuator after the input stage. The advantage to this last topology lies in the consistent bandwidth and distortion between channels is better preserved, as each input stage will see the same input impedance from the volume control and will see the same amount of voltage swing.





In the second of the above circuits, we see a series attenuator bridging the input grounded-cathode amplifier to the output cathode follower. Because the attenuator terminates into a shorting capacitor to ground, the DC voltage relationships remain constant no mater what the attenuator's setting.

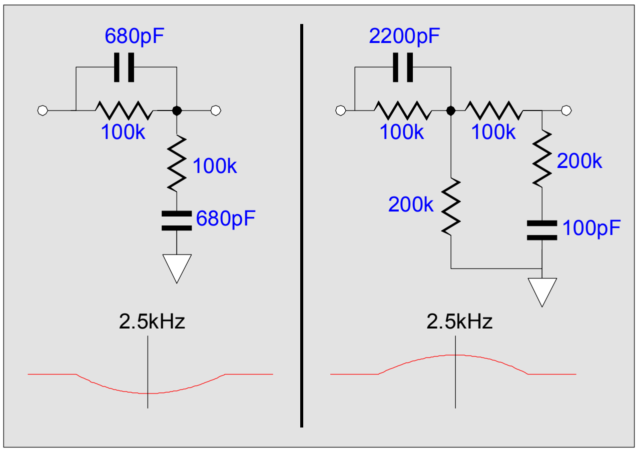
Phase Control: Minus and Plus

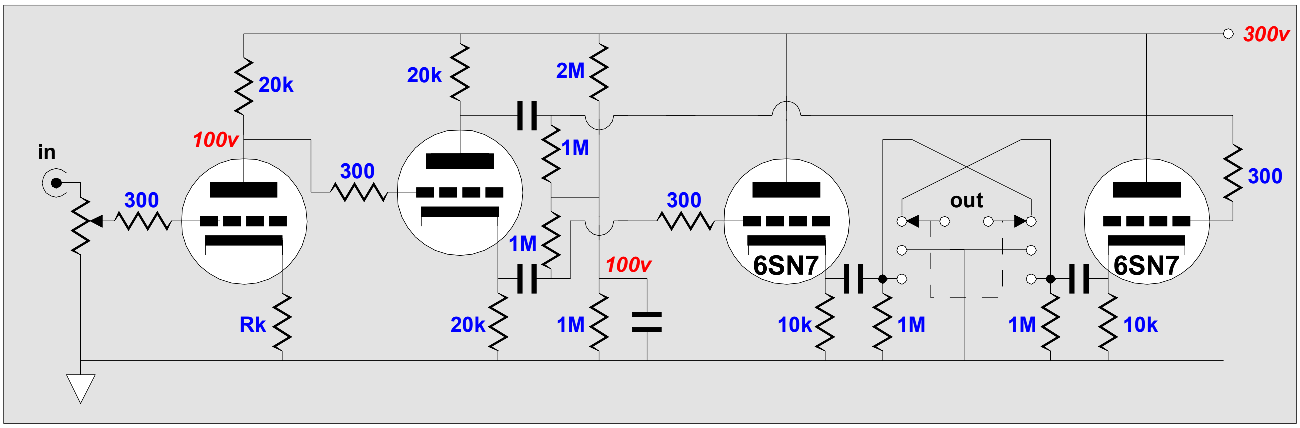
Controlling this aspect of the signal requires a balanced signal to occur somewhere in the circuit. If the input signal is balanced, our work is done for us, as we only have to switch phase at the input or the output. But if the signal is single-ended (unbalanced), then we must split the signal into two phases. Here the split-load phase splitter's superior balance recommends the circuit's use. As long as the plate resistor and cathode resistor match in value, this phase splitter will provide a balanced output signal. But as this phase splitter has dissimilar output impedances per phase, it should not be used as the final stage.

In the schematic below, we see the split-load phase splitter cascading into two cathode followers, which not only allows phase selection, but also a balanced output. The manner in which the phase is selected is important. The worst-case scenario is the two-position toggle switch. The ear requires a quiet pause in which to reorient itself to the phase's reversal, which the snap of the toggle switch denies. A better choice, therefore, is a three-position toggle switch or (better still a rotary switch) with muting in the center position.

Position Control: Recessed and Close

A slight shallow dip in the 2000 to 3000 range creates the illusion of the sounds originating further back behind the loudspeakers. Conversely, a boost at these frequencies causes the sound to move toward us. The following circuits create the dip and boost required.





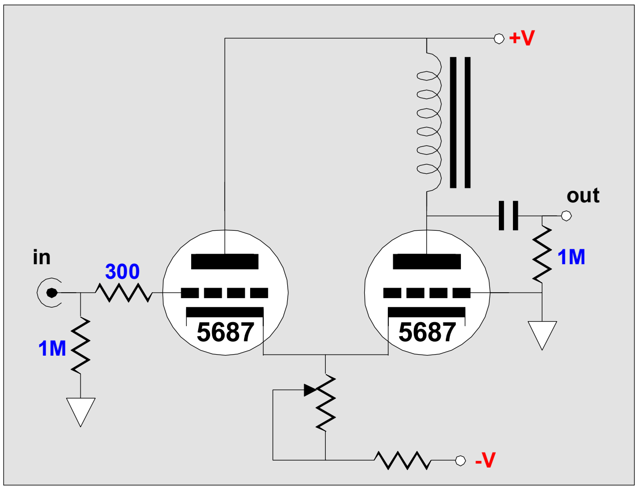
Height Control: Low and High

The ear interprets a fairly narrow boost centering at 8 kHz as a sound source above ear level. Conversely, it hears a dip centering at 8 kHz as a sound source at or below ear level. Implementing this control might require active equalization or at least a reactive network that includes an inductor.

Dynamics Control: Compressed and Explosive

I know of no better sonic compressor than a healthy amount of global feedback. (Actually, this control might be better labeled as the "Life Control.") Achieving the contrasting attribute might require positive feedback. Now positive feedback is definitely a dangerous thing, as it leads to oscillation and burnt-out voice coils. Moderating the positive feedback might require a negative feedback loop or a low gain tubes. (I once heard a hotrod Dynaco ST-70 modified by my friend, Lance, that used both positive and negative feedback. The sound was wildly exuberant, so much so that it was likened to the singer, Madonna, as many would love to spend a weekend with her, but none would want to spend a lifetime.)

I have also found that the amount of idle current can influence the perceived dynamics of the sound, with a low current sounding insubstantial, but dynamic; and a high current sounding solid, but a bit constrained. Possibly, the mechanism lies in the low idle current's working at the bottom of the triode's curve where the increasing transconductance with positive going signals is more pronounced.



Implementing a variable idle current usually runs the risk of wildly changing DC operating points, which could lead to dangerous voltage pulses at the output. Using a choke load would help to eliminate many of these dangers, as the DC shifts at the plate would only equal the change in idle current against the DCR of the choke, which is only a fraction of the comparable plate resistor. Shown below is a common-cathode amplifier that allows easy adjustment of the idle current by varying the common cathode resistor's value.

Weight Control: Light and Heavy

The impression of heft or weight is found in the deep bass response of a system and ideally synthesizing sub-harmonic information from the signal might create it. This would require digitally synthesizing these frequencies. A simpler method might be to apply a boost to the lowest frequencies. (A danger with either method is the potential damage to the woofers, as reproducing lower frequencies requires greater watts.)

Rhythm Control: Slow and Fast

Many of us grew up listening to sped up 45s over the radio (it allowed the radio stations to play more commercials I have been told). Today, when we hear these songs they seem slow. So in order to make the listening experience accurate to our history, and not any absolute, a speed control is needed. Ideally, a speed control for either turntable or CD player would be the way to go. Failing this direct manipulation, haven't we all heard amplifiers or oil coupling capacitors that sounded slow? Where does the perceived slowness derive? High frequency phase relationships, maybe? More research is definitely needed.

Temperature Control: Cool and Warm

No, heating the heaters extra hot is not the answer. But maybe having predominately even-order harmonic distortion gives a warm quality to the sound; just as a predominately odd-order harmonic distortion gives a cool quality? Differential amplifiers eliminate even harmonics, which effectively boosts odd harmonics. And single-ended grounded-cathode amplifiers create a good amount of second harmonic distortion. Selectively blending between these two circuits may be the answer.

Illumination Control: Dark and Bright

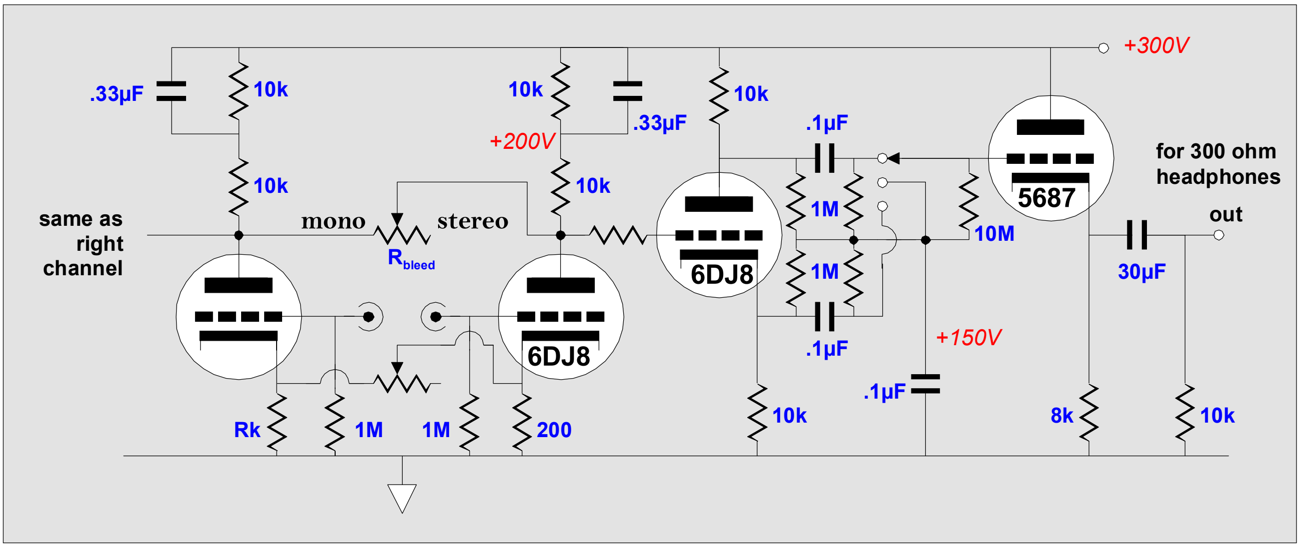
Skewing the high frequency response (above 6 kHz) up or down creates a bright or dark sound. Coupling capacitors can also create a dark or bright sound. For example, to my ears, the red Wima capacitors often sound dark, whereas the MIT capacitors often sound bright (if not a bit metallically clanky). So boosting or attenuating the high frequencies and/or switching coupling capacitors might work well.

Texture Control: Soft and Hard

How do proceed? Solid-state Vs. tube? Different coupling capacitors, resistors, tube types? We all know a soft or hard sound when we hear it, but how do we create it? Is soft the same as blurry because of microphonics? Is hard the same as harsh harmonics such as the 5th and 7th? Or is it something else altogether? My guess is the latter.

Depth Control: Shallow and Deep

This is not the same thing as position control. The issue is not how close are the musicians, but how far back does the hall they performed in go back. Some audiophiles use a second set of subwoofers, situated several feet behind and out from the primary subwoofers. These add readily hearable increase in perceived depth. Possibly, adding a time delayed low frequency signal to the mix could mimic this effect. (Capacitive bucket delay lines would work well, as their high frequency bandwidth limit would not be reached by those exclusively low frequency signals.)



Tone Control: Thin and Rich

Tone does not mean the same thing "Tone" usually means when followed by "Control," as it does not refer to more (or less) low or high frequencies, but rather to something like sustain in a musical instrument. Some coupling capacitors, resistors, and some tubes are said to have a big tone. Maybe it is the result of beneficial microphonic resonances. Maybe adding small loudspeaker inside the chassis would allow an adjustable amount of mechanical feedback. Or maybe a hint of frequency selective positive feedback is the answer.

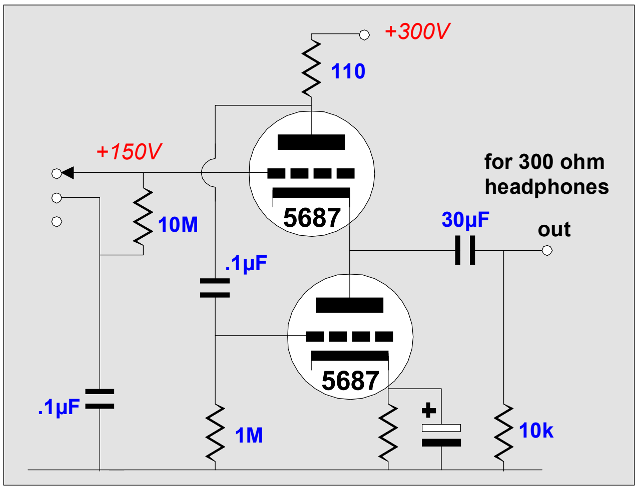
Headphone Listening

It's a common sight, the bass-boost control on portable radios and CD players. So many users leave this boost permanently in place that I am surprised that it is offered as an option and not hardwired into the circuit; but as a nod to the absolute sound, the boost remains an option. And although the applied boost is too heavy handed, we can readily discern that it is a move in the right direction, as a flat frequency response in a headphone sounds wrong, too thin, too bright. How is this possible?

The answer lies in the fact that we do not hear with eardrums alone. Our ear's shape and our haircuts alter the sound before it enters the ear cannel. And our bodies hear-feel (somatosensory perception) the deep bass notes.

Our head is not large enough to prevent one ear from hearing anything that the other ear hears, creating a blended sound at each ear, involving frequency tailoring and phase shifts, all of which headphones prevent. Because headphone listening lacks these components, we need a set of controls specific to headphone use. If nothing else, a stereo-blend control and a simple bass boost would help make headphone listening more enjoyable.

The circuit above shows a simple headphone amplifier for 300-ohm headphones. It includes a fixed +6 dB bass boost, image width control, and a phase selection switch with mute in the center position. (Driving lower impedance headphones requires paralleling several output triodes or using a White cathode follower.)



Conclusion

This has been more of a philosophic article than a how-to article. Asides from the balance and width control and phase control, these sonic controls must be invented. Unfortunately, since 99.99% of the professional audio amplifier designer's research time is spent on how to reduce amplifier distortion from 0.0003 to 0.0001% and the golden eared are proudly non-technical, we do not have a vast body of research to fall back on. It is sad to reflect on early death of Alan Blumlein, the brilliant inventor stereo. He patented stereo in 1933 and he had an amazingly deep understanding of the principles underlying the actual perception of an acoustic event. For example, he knew that the pan-pot approach used in all modern recording studios is inadequate to the task of moving the perceived position of a sound without smearing the sound, as there must also be a frequency selective compensation. No doubt, had he lived into the end of the last century, all our stereos would sound much better as a result. In his absence, we will have to carry on his work.

//JRB

Further Readings

"Alan Dower Blumlein," Robert Alexander, *Electronics World*, Mar. 2000

"Improving Stereo Image Sharpness," F.O. Edeko, *Electronics World*, Oct. 1998

"Image Movement in Stereophonic Sound Systems," F.O. Edeko, *Electronics World*, Oct. 1998

"Improve Your Image," Richard Brice, *Electronics World*, Oct. 1998

"Stereo from All Angles I," John Watkinson, *Electronics World*, July 1999

"Stereo from All Angles II," John Watkinson, *Electronics World*, Aug. 1999

"Stereo from All Angles III," John Watkinson, *Electronics World*, Nov. 1999

"Stereo from All Angles IV," John Watkinson, *Electronics World*, Jan. 2000

"Stereo from All Angles V," John Watkinson, *Electronics World*, Mar. 2000