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By Erik Owen

## Glass Audio Special

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## Revival of the McIntosh MC30

By Bruce Brown

## Mu Stage Update (An Outrageous Mu Stage)

By Alan Kimmel

## Desktop Tube Headphone Amplifier

By Bill Reeve

## Budget High-Performance Valve Headphone Amplifier

By Bruce Heran

## A Second Life for a Vintage Tube Amp

By Mark Driedger

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Capturing the Acoustics of Musical Instruments  
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More Tubes, More Sourcing Options

Every year, when we work on our Glass Audio Special edition, we look back to reflect on the state of the tube market, particularly for hi-fidelity and high-end audio applications.

From our discussions with multiple companies that manufacture tube amplifiers, preamplifiers, and now ever more frequently, headphone amplifiers, the testimonies are the same. Sales, are increasing, both in the lowest, more affordable (but sometimes, still considerably expensive) categories, and certainly in the more sophisticated categories, with monoblock amps costing \$10,000 USD and more.

The hardest to sell products are “mainstream” stereo and integrated amplifiers that cost \$3,000 to \$6,500, which still sell to dealers and stores worldwide, but don’t captivate users in the same way.

When talking to brands that sell direct or have very exclusive sales channels, we commonly get the confirmation that products don’t stay long in the warehouse: “Build them and they will fly.”

And it’s not only about branded products. Tube DIY projects continue to be extremely popular and they are the most popular topics among the many articles that audioXpress makes available online. Coincidentally, when we looked back at what were the most popular topics and stories published online at audioXpress.com during the entire year 2018, number one was the announcement, in May 2018, that Western Electric was to reintroduce its famous 300B electron tube.

The return to production of the famous 300B electron tube with the reference to the 150-year-old Western Electric brand apparently triggered the interest of not only the regular audioXpress readership but also of a huge global community.

Entrepreneur and Western Electric CEO, Charles Whitener, in cooperation with AT&T, reestablished Western Electric and the Westrex Corp. resumed manufacturing the first 300B single-ended triode tubes in Kansas City in 1997. In 2003, the company moved 300B manufacturing to Huntsville, AL, and, in 2009, the company moved to Rossville, GA, where they are manufacturing electron tubes again, on a new and re-imagined facility.

Western Electric is currently accepting orders for the 300B vacuum tube, with shipments scheduled to start at the time of this writing. The new 300Bs are priced at \$1,495 per matched pair or \$695 for a single, offered with a 5-year limited warranty.

Eighty years old, the 300B is returning once again to capitalize in the strong popularity of tube-based high end audio systems and meet renewed demand around the world. And Whitener did not stop there, introducing the WE 91E, a single-ended, 80<sup>th</sup> anniversary edition integrated amplifier, and an homage to its famous predecessor the 91A, first introduced in 1936. And there’s also a stunning limited edition, monoblock version of the 91E called the 91C Metropolis, with a design inspired in the Fritz Lang’s movie, with an expected MSRP of \$9,995.

Meanwhile in Europe, our colleague Ward Maas also noted in his High End 2018 report that Thomas Mayer is working hard to develop the product program for the Deutsche Elektronenröhren Manufaktur GmbH, which took over as the new manufacturer of ELROG tubes (www.elrog.com) in August 2016. This company had its roots in the well-known Telefunken tube activities and they now have production running of their own ER300B, joining the introduction one year ago of the Elrog 242, a molybdenum plate version of the ER211, the ER274A (octal base) and the ER274B, the ER242, and the ER284, derived from the original ER845. All the new ELROG tubes received significant changes to solve quality issues and the company already confirmed new models will be announced at High End 2019.

At the High End Munich show last year, plenty of exhibitors also referenced their own “improved” tubes, meaning actually modified versions of the KT66, the KT77, the KT88, the KZ120, and others, which are manufactured to specification by existing manufacturers.

So, it’s not only new-old stock (NOS) tubes that continue to do well—as any Internet search for tube vendors will reveal. With this level of activity, we have no doubts that—much like vinyl—tubes are going to stay around for a very long time.

J. Martins  
Editor-in-Chief

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COLUMNISTS

**Vance Dickason** has been working as a professional in the loudspeaker industry since 1974. He is the author of *Loudspeaker Design Cookbook*—which is now in its seventh edition and published in English, French, German, Dutch, Italian, Spanish, and Portuguese—and *The Loudspeaker Recipes*. Vance is the editor of *Voice Coil: The Periodical for the Loudspeaker Industry*, a monthly publication. Although he has been involved with publishing throughout his career, he still works as an engineering consultant for a number of loudspeaker manufacturers.

**Mike Klasco** is the president of Menlo Scientific, a consulting firm for the loudspeaker industry, located in Richmond, CA. He is the organizer of the Loudspeaker University seminars for speaker engineers. Mike specializes in materials and fabrication techniques to enhance speaker performance.

**Dr. Richard Honeycutt** fell in love with acoustics when his father brought home a copy of Leo Beranek’s landmark text on the subject while Richard was in the ninth grade. Richard is a member of the North Carolina chapter of the Acoustical Society of America. Richard has his own business involving musical instruments and sound systems. He has been an active acoustics consultant since he received his PhD in electroacoustics from the Union Institute in 2004. Richard’s work includes architectural acoustics, sound system design, and community noise analysis.

**Steve Tatarunis** has been active in the loudspeaker industry since the late 1970s. His areas of interest include product development and test engineering. He is currently a support engineer at Listen, in Boston, MA, where he provides front-line technical support to the SoundCheck test system’s global user base.

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## ● Glass Audio Special

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By Bruce Brown

Many *audioXpress* readers are familiar with McIntosh and its high-end products. Bruce Brown rebuilt and restored many versions of the company's tube amps. This article focuses on the restoration and some improvements to the MC30 mono power amplifier.

### 32 A Second Life for a Vintage Tube Amplifier

By Mark Driedger

Just for fun, Mark Driedger decided to revamp his old Electra EL-3000. Maybe this article will inspire others to revisit some of their past projects.

### 36 Build a Budget-Friendly High-Performance Valve Headphone Amplifier

By Bruce Heran

Learn how to build a simple valve headphone amplifier. There are no capacitors, it is easy to configure, and sounds very nice.

### 40 Desktop Vacuum Tube Headphone Amplifier

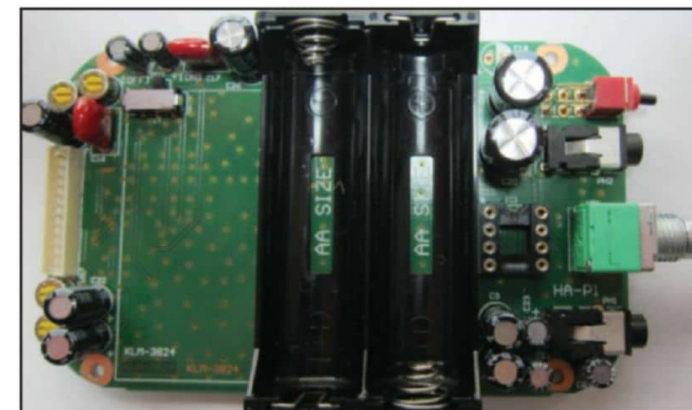
By Bill Reeve

Bill Reeve shares one of his longtime favorite designs—a vacuum-tube-based headphone amplifier that could also be used to drive small desktop speakers.

### 42 An Outrageous Mu Stage An Update of My 1993 Mu Stage Design

By Alan Kimmel

Alan Kimmel has built and tested many circuits over the years and he believes the Mu Stage is capable of producing the most constant-current operation as well as very low output impedance. After revisiting a design concept more than 20 years after he first shared it with audiophiles, Kimmel is back to divulge some of the most recent updates of his Mu Stage.



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By Erik Owen

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By Brian Lowe

Voltage regulators have many specifications such as output current, noise, drop-out, input ripple rejection, and dynamic load transient response. This article examines a search for a true measurement of ripple rejection, also called power supply rejection ratio (PSRR).

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# Miking Instruments

## A Few Techniques

To properly mic an instrument, it is important to first listen to the instrument before placing the microphones. It is also recommended that you experiment with various microphones prior to making a final selection.

By  
**Richard Honeycutt**  
(United States)

Too often microphones are selected and positioned based on past experiences and industry tradition. The microphone is selected and placed in a specific position in front of the instrument just because this is the way everyone else is doing it. Sound sources can be complex, especially in the near field. Some parts of a musical instrument may act like a point source. Others may act like line sources or plane sources. This is why the perceived sound, the timbre, may change a lot when moving the microphone in the near field of a musical instrument. The level of the point source drops

by 6 dB per doubling of the distance. Line sources drop by 3 dB and plane sources do not drop at all! At some distance (a few meters away), the instrument eventually becomes a point source, but close-up, many theoretical models are possible. The size of the radiating surface is also an important controller of the sound radiation: Sources having dimensions equal to or larger than the wavelength at a particular frequency can radiate directionally, but smaller sources will be essentially omnidirectional. This is why it is important to listen to the instrument before placing microphones.

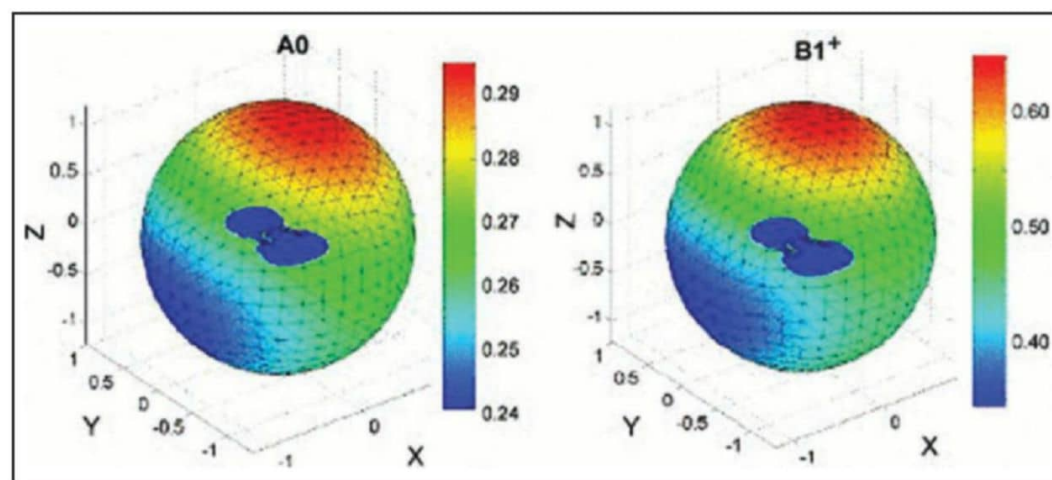
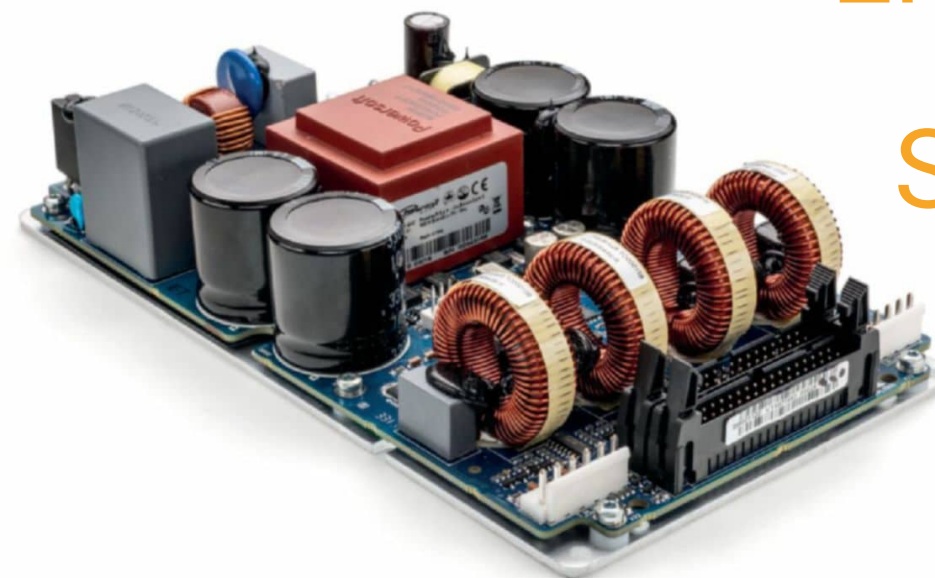


Figure 1: Directivity of radiation of a violin at 270 Hz and 521 Hz

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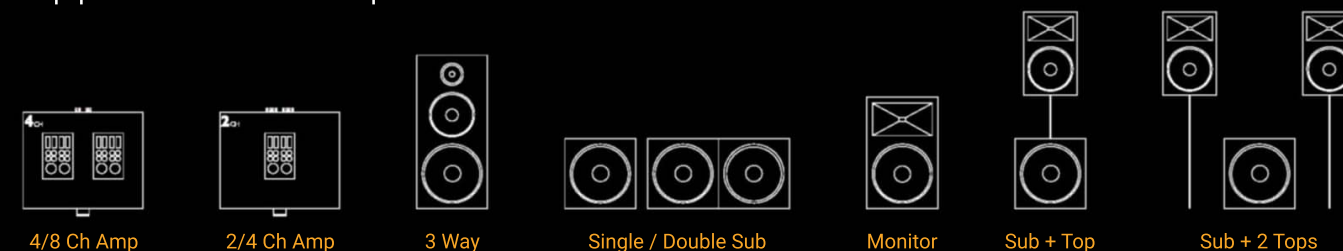


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## Application Examples





### Recording

In studio recording situations (and some live recording as well), an instrument may be miked from several meters away, but in live sound, fairly close miking is usually needed to preserve

acoustical gain before feedback. If you are close-miking instruments, you can access advice from many sources—some good, some not-so-good—for what mic to use and where to place it. But if you often listen to live performances of the kind of music you're recording or amplifying, so that you have "calibrated hearing," you can start with a simple procedure. Do yourself a favor and listen to the instruments requiring close-miking. Listen with your ears close to—and move around—the individual instrument. Then select a microphone and do the same. Listen through headphones

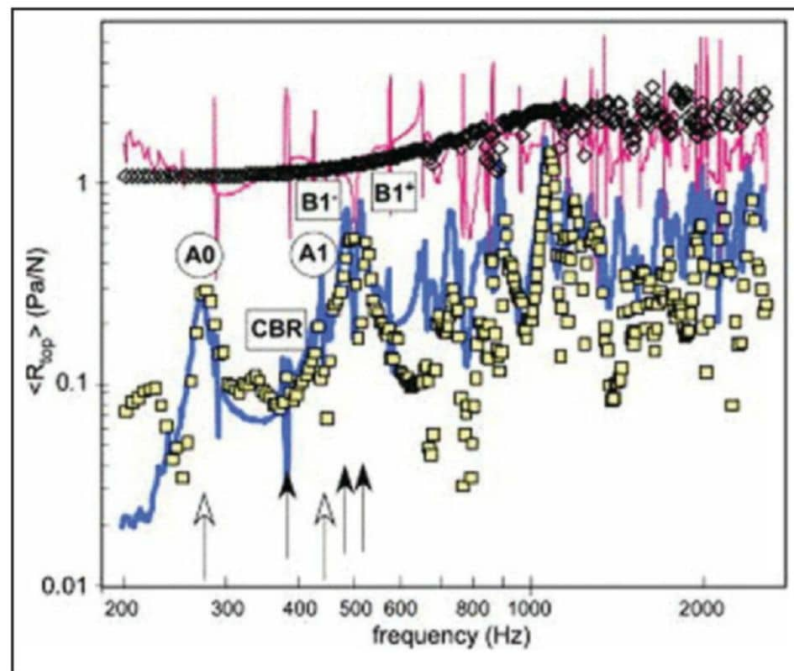


Figure 2: Radiativity and directivity of a violin between 200 Hz and 2000 Hz

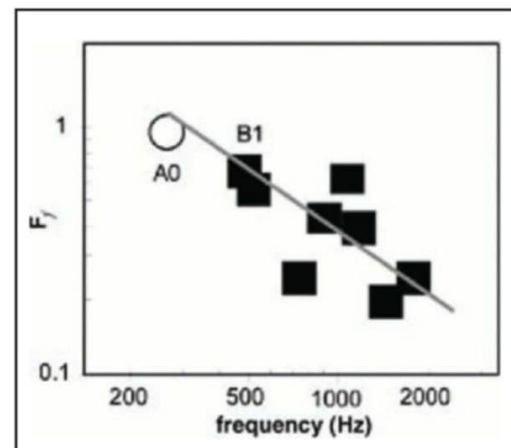


Figure 3: Fraction of sound radiated from the f-holes of a violin between 200 Hz and 2000 Hz

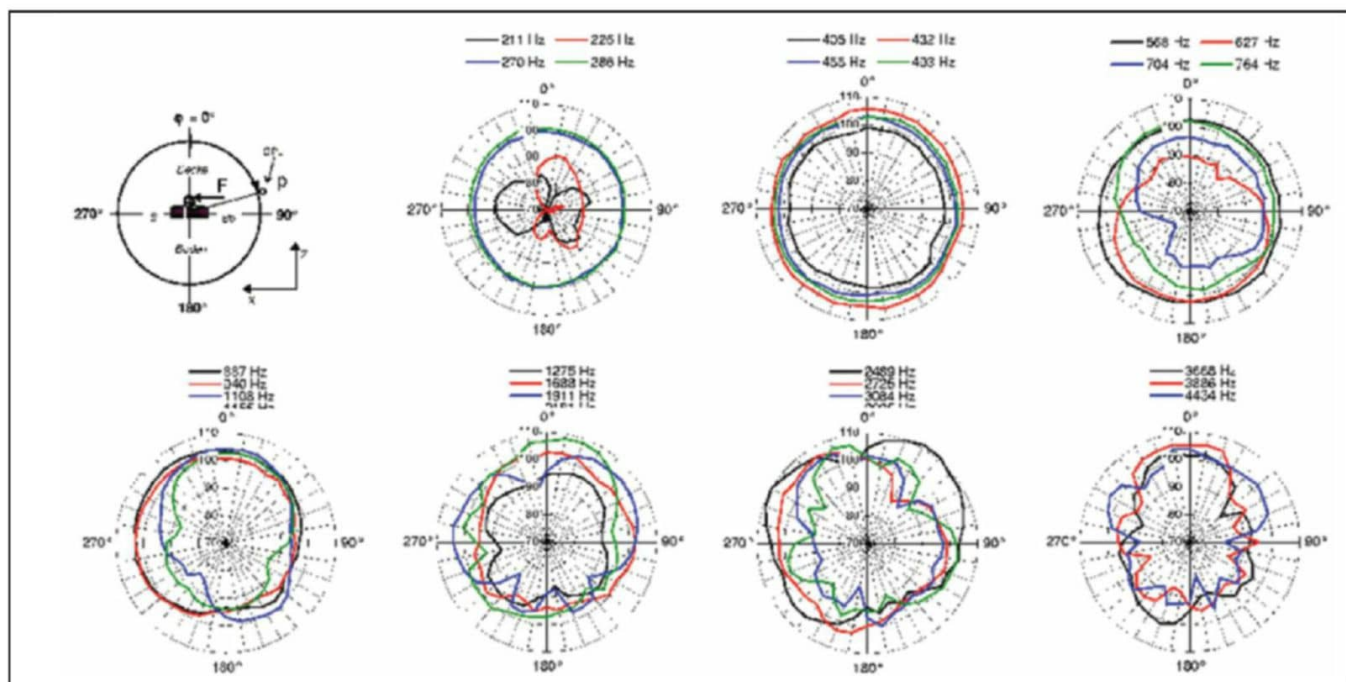


Figure 4: Directional radiation patterns of a violin



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while “sweeping” the microphone across the surface, the strings, the bell, the rim, and the body of the instrument. Pick another microphone and repeat the procedure. If it is a directional microphone, check the sound by turning your microphone to both on-axis and off-axis positions. By doing this, you will hear that each and every instrument and microphone has a unique sound. No two cellos, flutes, saxophones, kick drums, and so forth sound quite the same. There may exist alternative microphone positions for each individual instrument.

### Positioning the Microphone

Of course, there are occasions when we do not have time to go through this general process to find the best mic position. And there is still the question of what mic is best for the job. Let’s go through some background in the field of musical acoustics: the acoustics of musical instruments.

The violin has been studied extensively by musical acousticians. **Figure 1** illustrates the radiation from the f-holes of a violin at low-frequency modes A0 (270 Hz) and B1+ (521 Hz). The colors represent (roughly) sound level, ranging from lowest (dark blue) to highest (red). Not all the characteristic sound of a violin is radiated from the f-holes, as indicated in **Figure 2**.

The lower curves represent the radiativity

from the f-holes (□) versus radiativity from the top hemisphere of the violin (thick blue curve), for frequencies up to 2.6 kHz. The upper curves represent the directivity of the radiation from the f-holes (◇) versus radiativity of the violin as a whole (thin red line). (Note that the diamonds representing f-hole directivity sort of merge, giving the appearance of a thick black line.)

**Figure 3** simplifies the picture by plotting the fraction of total radiation of sound from the f-holes. Note that higher frequencies are mainly radiated from other parts of the violin.<sup>[1]</sup> **Figure 4** shows the radiation pattern of a specific Guarneri violin at different frequencies.<sup>[2]</sup>

The violin has been used as an example so far because of the large number of acoustical studies of that instrument. However, as illustrated in **Figure 5**, the guitar (and other stringed instruments) radiate sound according to similar physical principles. The term “lowest partial” is equivalent to “fundamental.” Thus the six images represent sound radiation from each of the open strings. Assuming standard tuning, these would be E<sub>2</sub> (82.41 Hz), A<sub>2</sub> (110 Hz), D<sub>3</sub> (146.83 Hz), G<sub>3</sub> (196 Hz), B<sub>3</sub> (246.94 Hz), and E<sub>4</sub> (329.63 Hz).<sup>[3]</sup> Each string produces strong overtones in addition to the fundamental, and these overtones are essential to the timbre of the instrument. However, just from the frequencies illustrated

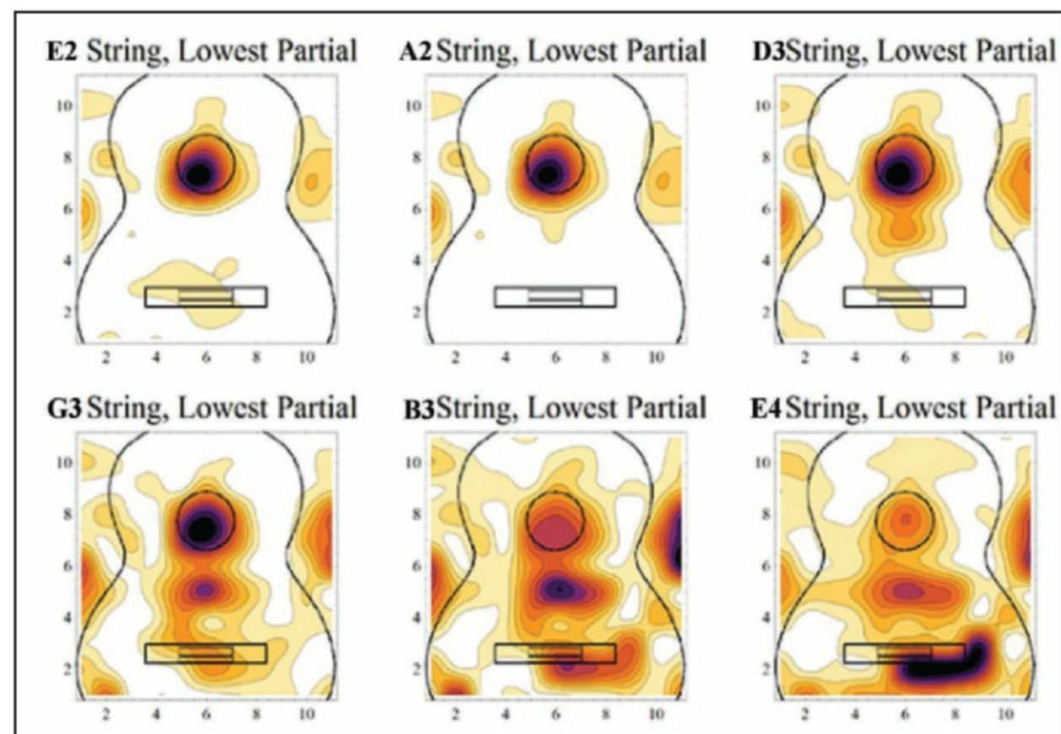


Figure 5: Portions of a guitar top from which most sound radiation occurs

in Figure 5, you can see that lower frequencies are radiated mainly from the soundhole, while higher frequencies radiate more from the bridge, especially the part of the bridge directly activated by the particular string. **Photo 1** illustrates three useful mic positions for an acoustic guitar. Position 1, at the soundhole, is the loudest, but also is



Photo 1: Locations for miking a guitar

usually rather bassy. Position 2, halfway between the soundhole and the bridge, is more balanced, and is probably the best place to start. Position 3, near the soundhole end of the fingerboard, is best for some guitars.

Brass instruments radiate sound primarily from the bell, and like most acoustic horns,

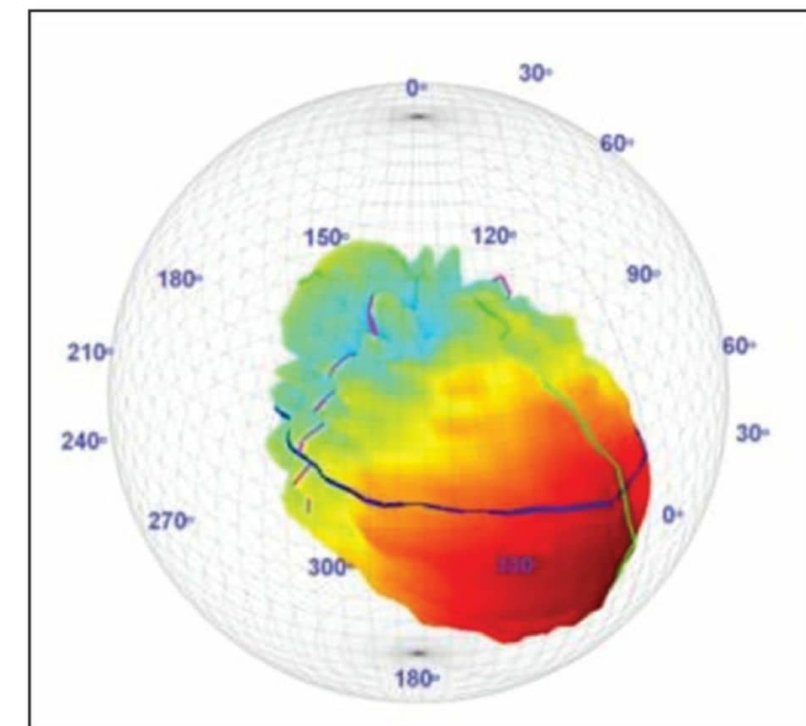


Figure 6: Directivity balloon for a trumpet playing a 4-kHz note (The trumpet bell is in the center of the virtual balloon, aimed down and to the right.)



Photo 2: Miking a flute



Photo 3: Starting point for miking a bagpipe



“beam” high frequencies. Essentially what happens is that roughly the first quarter-wavelength of a particular wave is constrained in its directivity by the horn flare. Since the flare angle increases as you move toward the horn mouth, so does the radiation coverage angle. This effect interacts with the requirement that a circular radiating surface be a substantial fraction (roughly half) of a wavelength in diameter in order to radiate directionally at a particular frequency. Thus, a trumpet, having a bell that terminates at about 4.75” in diameter, is essentially omnidirectional below about 2.8 kHz. **Figure 6** shows a directivity balloon for a trumpet at about 4 kHz (four octaves above middle C, or the third harmonic of a “high C”). For higher harmonics, the trumpet becomes even more directional. This is why miking a trumpet on-axis will give you a very shrill sound that is hard to EQ enough that it sounds right. The same is true for all brass instruments.

Reed instruments (e.g., oboe, clarinet, sax, etc.) emit sound mainly from the valve holes (i.e., all along the body of the instrument). Although this sounds like it would make miking almost impossible, actually, miking in a position from which a listener would hear the instrument works quite well. For the clarinet, the bell is normally pointed toward the floor, and the listener is hearing floor reflections from in front of the instrument. Ditto for the other woodwinds. For the sax family, miking at the bell can work well, even though some EQ may be required.

The sound of a flute is mainly radiated from the hole where the player blows, so miking just in front of that hole works well (see **Photo 2**).

One wind instrument that is seldom well

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[1] G. Bissenger, Physics Department, East Carolina University, Greenville, NC: “Violin f-hole contribution to far-field radiation via patch near-field acoustical holography,” *The Journal of the Acoustical Society of America* 121, 3899 (2007); <https://doi.org/10.1121/1.2722238>

[2] M. Schleske, “... Introduction: Violin Acoustics - Sound Analysis - Method,” <http://www.schleske.de/en/research/introduction-violin-acoustics/sound-analysis/method.html>

[3] R. Bade, Institute of Musicology, University of Hamburg, Germany R.Bader@t-online.de Lay-language version of paper 3aMU7, “Acoustic Holography of Musical Instruments using Radiation Directivity Method,” presented on November 12, 2008, 156<sup>th</sup> Meeting of the Acoustical Society of America.

miked is the bagpipe. The high-frequency sound is radiated from the chanter (the thin pipe that the player fingers), but the low frequencies are radiated from the drone pipes. The chanter is in front of the player, below waist level, while the drones are behind him/her, above shoulder level. Miking to get a proper balance between chanter and drones is a matter of balancing spacing as illustrated in **Photo 3**. The mic is placed on the side of the player opposite the drone pipes, roughly halfway vertically between the chanter and the drones. Experimentation will be required!

There will doubtless be some readers who are wondering who on earth would want to mic a bagpipe! It is true that the bagpipe is a very loud instrument. That fact, coupled with their particular timbre, is said to have caused German soldiers during World War II to dub the Scottish Highland troops, with their regimental bagpipers, as “the ladies from Hell.” But although bagpipes can usually hold their own level-wise in most ensembles, you may need to record a bagpipe sometime!

Miking guitar and other instrument amplifiers depends upon knowing a bit about the speaker arrangement. Most guitar amps have one or more cone speakers, each reproducing the same signal. You can mic these directly in front of one of the speakers, but preferably not in the speaker’s center. Speakers beam, as illustrated in the directivity balloon in **Figure 7**. At frequencies above 1 kHz, the beaming is more pronounced, and over-accentuating the high frequencies can lead to a harsh sound if the mic is aligned with the speaker’s central axis. Placing a mic about halfway between the center and the edge of one of the loudspeaker drivers often works well (see **Photo 4**).

Another consideration in miking instrument amplifiers is the maximum SPL the mic must be able to handle. Most pro-grade dynamic mics will have no trouble on this score. However, a few early (pre-1990s) capacitor mics, particularly electret models, were not clean at sound levels above about 95 dB<sub>SPL</sub>. Aside from instrument amps and bagpipes, the instruments most likely to need your attention with regard to high SPLs are percussion instruments. Kick drums, in particular, require careful attention to mic choice.

Several manufacturers of pro mics provide good application information that can be quite helpful. Notable among these is DPA Microphones ([www.dpamicrophones.com/mic-university](http://www.dpamicrophones.com/mic-university)). **ax**



Photo 4: Miking a guitar speaker

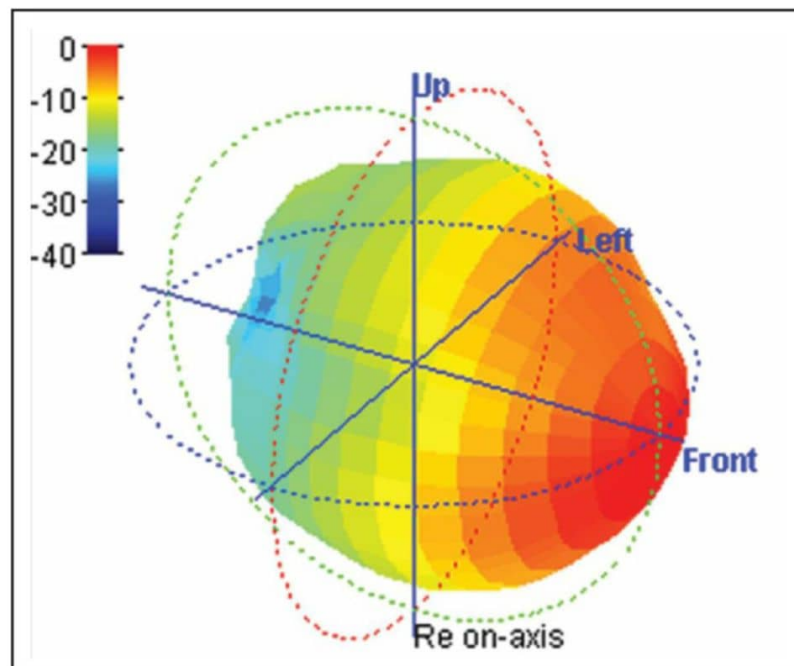


Figure 7: Directivity balloon for a 12” guitar speaker at 1 kHz

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# The Nu:Tekt HA-K1 “Tube” Headphone Amplifier by Korg/NuTube

## Power, Psychology, and Distortion

By  
**Erik Owen**  
(Gig Harbor Audio)



Erik Owen took home the Nu:Tekt HA-K1 headphone amplifier designed around the Korg NuTube 6P1—a miniature, low-power dual directly-heated triode that uses a one-pixel vacuum fluorescent display (VFD) device, emulating the properties of a driver tube. To design a portable device using the Nutube 6P1 is interesting enough, but to make things even more interesting, the HA-K1 is sold exclusively as a kit.



Photo 1: The NuTekt headphone amplifier kit by Korg

On the last day of the Rocky Mountain Audio Fest (RMAF) 2018 in Denver, CO, I bought a Nu:Tekt HA-K1 headphone amplifier for \$199 directly from the Korg Electronics/NuTube representative. It was not until I buckled into my seat on the flight back to Seattle that I realized the headphone amp was in the form of a kit: bags of capacitors, resistors, and soldering instructions (see **Photo 1**). So instead, I drank a noise-cancelling gin and tonic with my Bose QC35s plugged directly into my phone.

I have never really looked forward to listening to music through headphones, rather it just helps power through a flight. One of my goals in going to RMAF this year had been to finally find a pair of headphones I enjoyed enough to sell at Gig Harbor Audio (my own store in Washington, serving the local hi-fi community). I wanted something cool looking that produces warm detail like my dad’s Kenwood headphones from 1979.

The reason I came away from RMAF with a headphone amp and no headphones is simple: other

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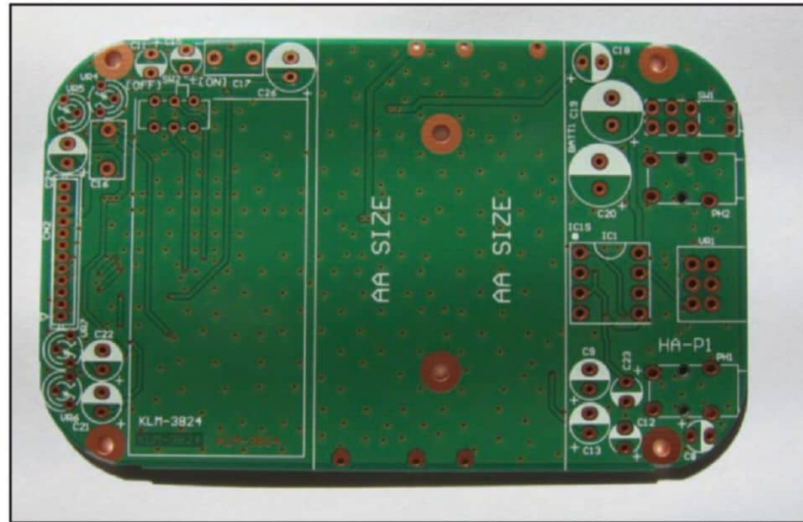


Photo 2: This is the board provided with the kit.

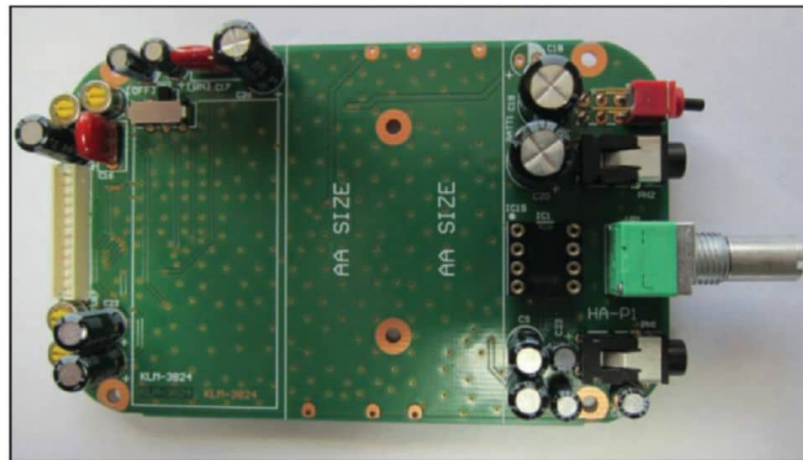


Photo 3: Once the soldering is done, it is time to connect the parts.

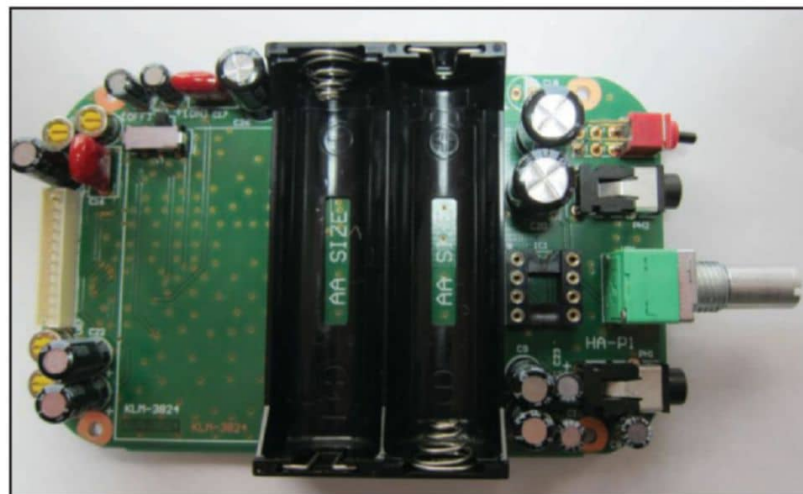


Photo 4: After everything is assembled, it is time to plug in the batteries.

people's heads. Walking into the "Can-Jam" hall where an ocean of headphone companies displayed their products, I decided that I was not going to press two sponges to my ears that have rubbed up against 300 other heads. Seriously. A headphone is a personal item. I would rather shell out \$5,000 for a pair of Stax sealed in the box without even listening to them than try on a pair that someone else has used. This article is not about headphones, but they do turn out to be one of the keys to understanding a small piece of innovation that I purchased on a whim: a miniaturized vacuum tube amplifier that the company Korg has apparently begun to perfect.

## Assembling the Kit

Once I got back to Gig Harbor I gave the kit to my tech Vladimir Belov (my soldering skills are just okay and my skills at following instructions are worse). According to the instructions that came with this amp, it has a triode that is structured with an anode, a grid, and a filament in a vacuumed glass body. The "tube" looks like a couple of Listerine melt-away gels side-by-side between extremely thin glass. Korg says it uses 2% of the power required by conventional tubes and occupies 30% less volume, as well as offering up to 30,000 hours of operating life. According to Vladimir, the instructions were fairly clear except for one mistake in the sequence: 1. In the "Building the Main Circuit Board" section, the second part of #2 (volume VR1-29) should be the second part of #9. It would be difficult to build this kit, if not for correcting their instructions (see **Photos 2-4**). The amp is 26 V for the op-amps, 2-AA batteries, and lasts about 9 hours.

## The Sound

Let's get into what it sounds like fully assembled. I used Sennheiser HD280 headphones. The source was my 13-year-old daughter's Gen 2 iPad Mini playing downloads from Apple music. (I wanted a source that did not use the Lightning to 3.5 adapter.) The first track we played was "Problem" by Ariana Grande. I could not pick out much of a difference between plugging direct to the iPad or going through the NuTube amp. If anything, the bass seemed bigger running straight from the iPad. We listened to "Call Me, Maybe" by Carly Rae Jepsen, "Fancy" by Iggy Azalea, and "I Kissed a Girl" by Katy Perry. All the same results. The Korg did not seem better than the simple Apple iPad.

I took a break before listening to more. After lunch and black tea, I cued up... "Baby One More Time" by Britney Spears, a great track from my daughter's folder as it was surprisingly rich and grainy for a collection of digital sounds. The vocals



Photo 5: This is how the Nu:Tekt amp should look when fully assembled.

were clear. The mid bass dynamic. Going from the iPad, then into the NuTube amp, after one play, I finally realized that I had been focusing on the sound incorrectly. Like a 3D poster I heard the difference pop. Instead of bass extension and loudness/gain, this Korg amp presented music more digestible, imaged, and what I consider as less fatiguing. Once I understood what to listen for, the Korg amp presented songs where I could see the whole extension of bass and the whole landscape of detail. I could see the image. Straight from the iPad the bass wasn't actually bigger, rather it had no limit, no beginning, and no decay. I could not see where it was stopping and coming back. Straight from the iPad, the music reflected like a row of mirrors with no ceiling or floor. The Korg amp presented a pleasant, medium-sized room with Britney singing a song, her DJ next to her with bass and textured synth coming out of Roland and Yamaha amps. I could see the DJ's quarter-inch patch cables on the floor. I certainly didn't feel like the amp made the music purer, perhaps the opposite. A full-sized integrated tube amplifier does not usually make music sound purer, rather it colors the music with its own flavor. When I look at a beautiful red sunset, it is not because the air quality is unusually pure, quite the opposite.

## About the Author

Erik Owen holds a Masters degree in English Literature/non-fiction from Western Washington University. From 1994 to 2010, he worked for various organizations internationally including USAID, the United Nations, the American Bar Association, and the Mercy Corps. He opened Gig Harbor Audio in 2012 in Washington state. Gig Harbor Audio focuses on musical two-channel tube and solid-state hi-fi as well as AV/home automation and hi-fi repair of turntables and amplifiers specializing in Marantz, Bang and Olufsen, Sansui, Krell, and any tube equipment.

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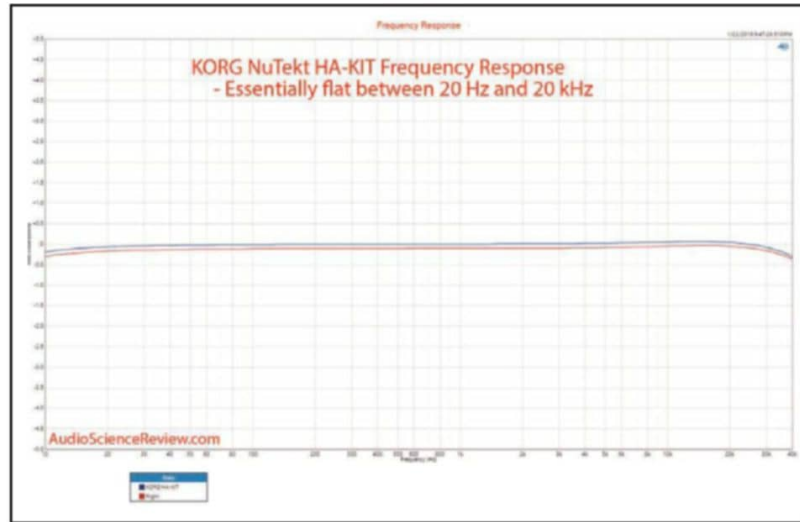


Figure 1: The frequency response of the Nu:Tekt amplifier. (Image courtesy of Amir Majidimehr)

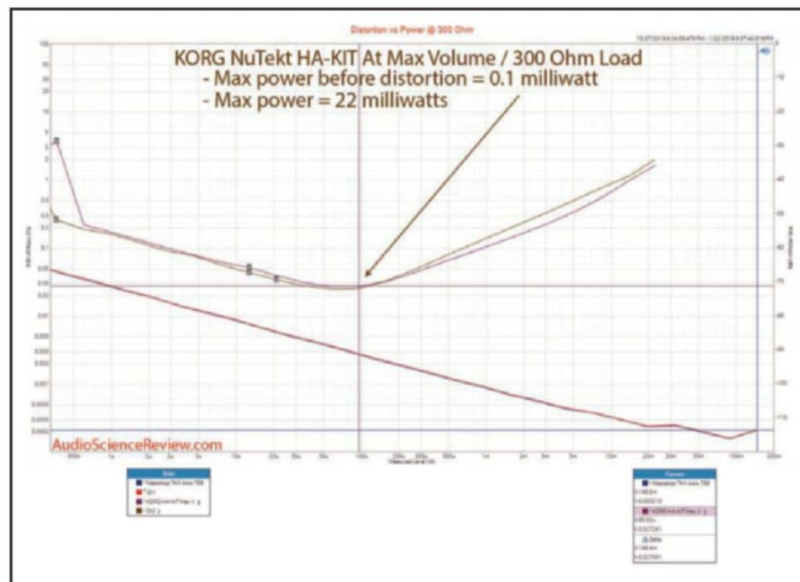


Figure 2: This graph shows the distortion vs. power. (Image courtesy of Amir Majidimehr)

## Resources

P. Millett, "The Korg Nutube 6P1," *audioXpress*, May 2017, [www.audioxpress.com/article/r-d-stories-the-korg-nutube-6p1](http://www.audioxpress.com/article/r-d-stories-the-korg-nutube-6p1)

Nu:Tekt, [www.nutekt.org](http://www.nutekt.org)

Amir Majidimehr, "Review and Measurements of KORG NuTube HA-KIT Headphone Amp," *Audio Science Review*, January 2019, [www.audiosciencereview.com/forum/index.php?threads/review-and-measurements-of-korg-nutube-ha-kit-headphone-amp.6401](http://www.audiosciencereview.com/forum/index.php?threads/review-and-measurements-of-korg-nutube-ha-kit-headphone-amp.6401)

Next, I had my daughter play the iPad alternating randomly into the headphones and through the Korg amp into the headphones. Each time my daughter triggered the beginning of "...Baby One More Time" by Britney Spears. Spoiler alert: I correctly identified the Korg amp 100% of the time. It was too easy as we went on with the experiment with the same song. We then played a new song twice through in its entirety: "K" by Cigarettes After Sex (streaming through Tidal). I listened to it all the way through on the headphones twice in a row. It was easy to differentiate once the second listening began. Listening to it the first time I was unclear as to which device was being used. After hearing the second play through I recognized it correctly as the Korg. In the first, the bass was uncontrolled and the simple acoustic guitar was too brilliant like a kaleidoscope. Through the Korg everything was in place in front of me, appearing like an image on a stage or a large platform. I could see the drums, the Virus TT synthesizer, and the beautiful feminine voice of Greg Gonzalez.

## A Scientific Approach

Let's look at some reasons the Korg sounds better than straight from the iPad. My friend Amir Majidimehr has a website called Audio Science Review where he recently did a review on this very Korg headphone amp that we put together. Unlike my review, Amir does not go into the songs he uses to test, nor does he comment much about how music makes him feel. His reviews are refreshingly science-based. He uses an APx 555 (Audio Precision analyzer) and mainly checks for levels of distortion. His graphs and charts are transparent and a good baseline for any product. Amir's review was, to say the least, not favorable toward the Korg/Nu:Tekt headphone amplifier. Through his charts, he shows the "frequency response is very flat, so anything you hear differently will be the result of distortion" (see **Figure 1**).

The Korg amplifier, according to Amir's results, is not that powerful, so the more the volume is turned up, the more distortion is produced. That was clear in my own listening as well. With the iPad maxed at 100%, basically using the Korg as an attenuator, the best sound occurred at about three-quarters volume on the Korg. This was loud enough for me, but probably not very loud on a consumer level, especially with less efficient headphones. After seeing Amir's results, it would appear that perhaps the actual distortion is what makes the sound seem more pleasant to me up to about 75% volume. It does reach a point above that where it seems to get a little crunchy. According to Wikipedia, (music) distortion is: "a change, twist, or exaggeration that

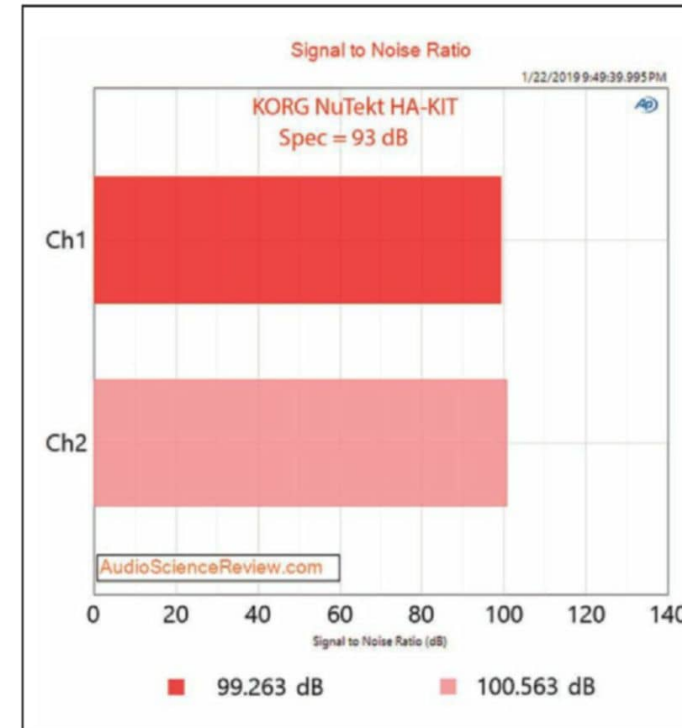


Figure 3: Here is the signal-to-noise ratio (SNR) shown right and left for this amp. (Image courtesy of Amir Majidimehr)

makes something appear different from the way it really is." I asked Amir if this distortion is like the "noise" that a guitar amp makes. He said kind-of, but not completely. The distortion or over-drive in a guitar amp is what makes it edgy and harsh, and fun. You don't want that in hi-fi. So, the "distortion" that he is talking about must be more on the side of "changing" or "altering" the sound instead of adding "noise" to the sound. I used to have a Casio CZ-1 synthesizer that had two different areas that you could change the sound: "noise" and "distortion." They were very different (see **Figure 2** and **Figure 3**). The distortion adjustments changed the flavor of the sound. The noise added static crunch like the guitar in a Nirvana song when Kurt Cobain stepped on that little box during the chorus.

Amir also did his listening tests differently. Instead of comparing a source like I did (the iPad) to the output from the Korg, Amir compared the Korg to a JDS Labs 02 battery-operated headphone amp by using a Y splitter from a single source. I decided I had better try that as well, so I ordered a JDS Labs amp online (\$149/free shipping). One other thing that Amir noticed in his tests on the Korg was that the internal right/left adjustment pots were slightly off with the right side being about 2% higher than the left. He could only see this by using his analyzer and made the adjustment so they were equal. This did make me wonder why I would buy a kit like this if I need a \$30,000 sound analyzer to make sure the right and left sides are equal. Amir quite logically explained that this does make a big difference in the way the image is presented.

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## Additional Testing

I received the JDS Labs amp in the mail four days later and used three different pairs of headphones to compare the Korg amp to the JDS amp: 1. Audeze LCD-X headphones (with a 0.25" to 3.5" adapter), 2. Sony MDR-V6s, and 3. Sennheiser 280. This time I used a MacBook Pro with a downloaded WAV file of "Waiting Room" by Fugazi (see **Photo 6**). Starting with the Audeze phones, and going from amp to amp, just like Amir said, the sound seemed extremely similar, the main difference being that the JDS indeed was a bit stronger output/higher gain. I listened for a good hour also noticing what



Photo 6: Here is the JDS Labs 02 battery-operated headphone amp that I tested using the song "Waiting Room" by Fugazi.



Photo 7: This is the Korg Nu:Tekt headphone amp that I tested using the same song "Waiting Room" by Fugazi.

Amir pointed out in his review that the Korg does give a slight thump when turning on whereas the JDS was stone quiet when pushing the on button (see **Photo 7**). Amir's phrase "...anything you hear differently will be the result of distortion" ran through my head during the listening. "Waiting Room" by Fugazi is a great song for comparison in that Ian KacKaye's vocals are super clear like he is in the room, the snare drum is sharp, and there is a dramatic silence right after the first 16 bars of which has a "noise floor" in the recording, likely from one of the guitar amps. The character of this noise floor (the sound of an amplifier being on) on the JDS amp sounded strong, full, and persistent. On the Korg, it sounded a bit softer, but more permeating, and more like noise from a guitar amp in a room.

It must be subjective that I like the Korg better. In talking with Amir, he said that when doing A/B listening tests he usually uses songs that are repetitive in their beat, techno tracks like DeadMau5. That made perfect sense to me. I tried it with "4Ware" from DeadMau5 and felt I was getting good listening material to chew on, but this track with its ethereal synth and driving 808 beats itself seemed to take over. I wanted to go back to four people in a room, to hear another test song without digital beats and processed layers. That is not the music I would usually listen to anyway. I wanted chalkiness and natural decay of real, forceful instruments. Angst and emotion, a good test, does not come through when click track triggered. When I hear drums, I want to hear the release of a person hitting a snare with a stick. Like Dave Grohl. Really hard. I had to get back deeper into the fundamentals, and one producer/artist who achieves that sound is Steve Albini. His recordings are unforgiving in the way they reveal. His music might not be the most pleasant for some people, but it is true. The song "Compliant" from Shellac's *Dude Incredible* LP is repetitive, droning, and perfect. The snare, high-hat, bass, and guitar have speed and decay showing a recording of people in a room. Before I go into what Shellac sounded like on both amps, let's talk about power in general.

One of my goals in hi-fi is making speakers (or headphones) "disappear" so I just hear the music. I have learned that more power is usually better, though not always. Making a speaker like a Focal, Harbeth, Bowers & Wilkins, Wilson, KEF, or Graham Audio disappear, the more power the better. Power is not necessarily for the purpose of playing it loud, but rather to be able to feel open-ness when the volume is down. On the other hand, Klipsch Corner horns, Belle's, Altec Voice of the Theaters, or Lowther full-range drivers prefer less power. The last time I

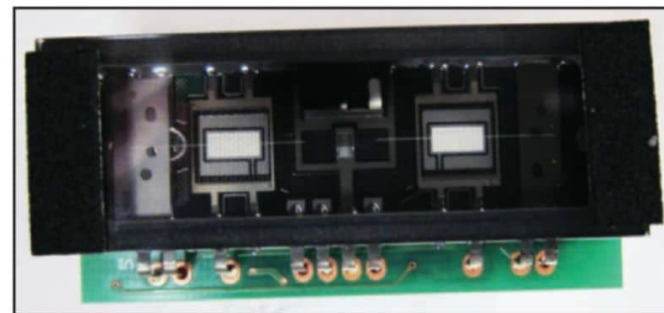


Photo 8: Korg Nutube's 6P1 mini tubes have ensured that this Nu:Tekt headphone amplifier will be in my carry-on bag (fully assembled) as I get on my next cross-Atlantic flight.

had Corner horns they sounded okay with an Exposure 3010 (100 wpc), better with a Heed Elixir (55 wpc) and better still with a Marantz 2245 (45 wpc). They started to really fall into place with a broken-in Dynaco ST70 (35 wpc on a good day). Then when I played them with a 3.5 WPC Hino tube amplifier they lit up with beauty and clarity. The bass felt like someone in the room playing a stand-up bass. Apparently, headphones react the same. Some like lots of power, some like less. Amir also pointed this out in that the Sony MCR-V6 headphones would be a good match with the Korg amp. He was right. I really found that a true A/B test between the Korg mini tube amp and the JDS solid state amp is impossible. They are different fruits. The Korg is not quite as strong, but there is something there that is pleasant.

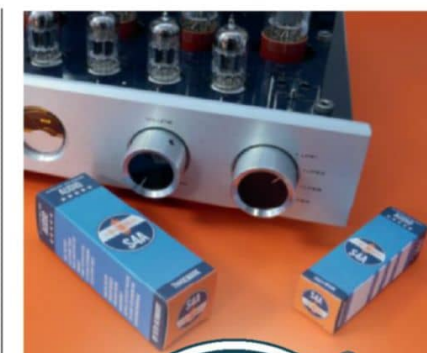
Now, using the song "Compliant" by Shellac, it was clear as day that the efficient Sony MDR-V6s sounded awesome with the Korg amp. I could hear the tempered consistency in the Albini recording rather than the automation of the DeadMau5 in the snare hits, and I could feel the rawness of Albini's guitar over and over and over, changing, distorting, evolving. With the same song, the Sennheiser headphones came to life with the JDS amp. The Korg just didn't have enough kick or power for them. It did not make them disappear. The Audeze headphones were engaging with both, but did seem to favor the power of the JDS.

Not recognizing at first the differences in sound character reminds me of one of my favorite books *The Screwtape Letters* by C.S. Lewis where an elder devil gives advice to a younger demon on how to keep a human from seeing the light: "...aggravate his neglect of the obvious. You must bring him to a condition in which he can practice self-examination for an hour without discovering any of those facts about himself which are perfectly clear to anyone who has ever lived in the same house with him or worked in the same office...".

The perception and presentation of the two headphone amplifiers is important. Better is subjective. Better according to Audio Science Review is based on precise measurements of distortion. We need Amir's view. We need some base line control. But is having distortion always bad? Take for example a bottle of organic/gluten-free cabernet wine that is 6 months old. It might very well be extremely clean when tested. But a bottle of 2007 Chateaufort-du-Pape, which is filled with sulfites and other toxins, is the bottle I would choose to open with a filet mignon. These sulfites and toxins distort the flavor of the wine, especially over time. Why would one listen to a tube-based amplifier in the first place? Isn't the whole point to have the tube in the middle of the signal path so it imparts its own character on the music? Tube amps seem to be often a little less power and a bit more character. Even my technician George Martin set aside his Krell 300 for a V1 Manley Stingray to power his Graham LS5/9s (yes, in a small room...).

## Conclusion

Two hundred bucks (\$249 retail) to carry around a device that makes my iPhone sound better, is a lot to ask. I also don't want something that will be antiquated in one year. In the late 1990s, I carried a flip-phone, a Canon ELPH camera, and a Texas Instruments pad with stylus. I did not consider cargo pants an innovative idea to accommodate all these devices. Combining the phone, the camera, and the note pad into one single device is innovation. This headphone amp feels not quite yet pret-a-porter. It is a flavor that does things that I like when paired with the right headphones, the right source, and the right Albini track. These tiny tubes (see **Photo 8**) that Korg came up with however, have ensured that this Nu:Tekt headphone amplifier will be in my carry-on bag (fully assembled) as I get on a Virgin Airlines flight to London. I'm looking forward to listening to some music with a gin and tonic.



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# Restoration and Revival of the McIntosh MC30 (Part 1)

## Rebuilding the MC30

By  
**Bruce Brown**  
(Vintage Tube Audio)

Many *audioXpress* readers are familiar with McIntosh and its high-end products. Bruce Brown has been a fan of McIntosh equipment for many years and has rebuilt and restored many versions of their tube amps. This article focuses on the restoration and some improvements to the MC30 Mono Power amplifier.

MC30s were produced from 1954 until 1962, at a price of \$153. This translates to about \$1,330 in today's dollars. This was for a single monoblock 30 W amp (see **Photo 1**). In 1962, the MC40 replaced it. The major difference between these two amplifiers was the elimination of the 5U4 rectifier and replacement with solid-state rectification. I currently own MC30s (I have six, two of which are relatively rare MacKITS) The MacKITS were only offered by McIntosh for around one year, and were a completely owner-built amplifier.

### The MC Amplifier Series

All of the MC series of tube amplifiers use very similar circuits and a comparison of their schematics show small differences among the 30s, the 40, the 60s the 75s, the 225s, the 240s, and the 275s in the stages up to the output tubes and power

supply. The 60s use the unused section of the first 12AX7 as plate voltage regulator for the input tube. Different output tubes, output transformers, and different power supplies are the main difference. I have never owned an MC225, but have restored a couple of them. They have a "different" sound, but are very McIntosh in layout and quality. I personally think the MC30s are the best overall tube amplifiers MC ever built. And, I think consumers tended to agree as more MC30s were built than all others in the series.

All of the MC series amplifiers used what McIntosh called "Unity" coupled output transformers. I think Roger Russell's explanation of this innovation is about the best I have seen. Russell said, "In a normal output circuit, using 6L6s in push-pull, the tube load impedance is 4000 ohms. A transformer is needed to match the typical speaker impedance of 8 ohms.

This represents an impedance ratio of 500 to 1. The necessary transformer turns ratio is the square root of 500, or 22 to 1. Leakage inductance and shunt capacitance cause high frequency roll-off. It also causes notch distortion in Class B operation."

He continued, "The Unity Coupled transformer distributes the load to the output tubes and effectively reduces the impedance to 1000 ohms. The impedance ratio is lowered to 125 to 1. The turns ratio is reduced to the square root of 125, or 11 to 1. Leakage inductance and shunt capacitance are greatly reduced. By using the bifilar winding technique, leakage inductance is eliminated between primary sections."

Russell concluded, "The Unity Coupled circuit and transformer reduced distortion compared to conventional amplifier performance at that time. The transformers were made exclusively by McIntosh."

These transformers were wound by McIntosh

and are quite complicated and difficult to rewind and expensive. They feature bifilar winding where several of the windings were wound at the same time. They also feature a continuous grain-oriented core of Hipersil ribbon that is split after it is manufactured to allow the winding to be inserted.

The specifications taken from the McIntosh Factory Construction Manual<sup>[2]</sup> for the amplifiers include:

- Frequency Response 20 to 30,000 cycles (Hertz) plus or minus 0.1 dB at full 30 W output
- 10 to 50,000 cycles (Hertz)  $\pm 0.5$  dB at full 30 W output
- Less than 1/3% harmonic distortion at 30 W output
- Hum and Noise 90 dB or more below rated output
- Damping factor 12 or better

Photo 1: I recently restored this McIntosh 30, which was produced from 1954 until 1962, at a price of \$153.

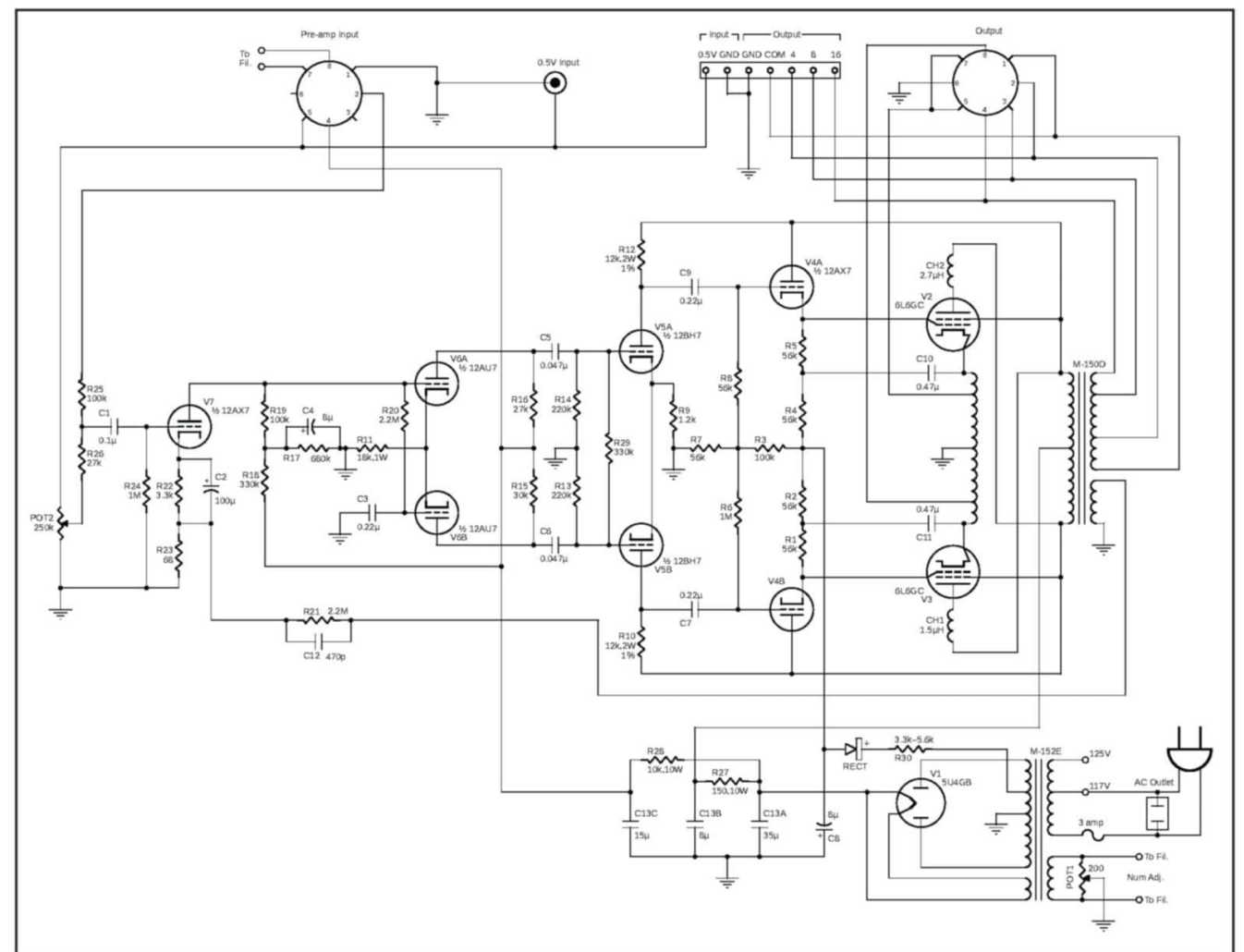


Figure 1a: This schematic for the MC30 came from the MacKIT Assembly Manual.



### The MC30

The MC30 used these tubes—the 12AX7 for the preamp, the 12AU7 for the phase inverter, the 12BH7 for the voltage amp, the 12AX7 for the driver, two 16L4 output tubes (6L6 equivalent), and one 5U4GA rectifier.

You will find many MC30s for sale on eBay, and you can also find many people who restore these amplifiers. Today, the going rate for an MC30 with tubes is between \$900 and \$1,500 each and rebuilt pairs cost approximately \$3,500. Most restorations are priced between \$300 and \$350 for electrical repairs and cost another \$300 to \$350 if you want a new chassis (or a re-chromed re-lettered one). However, you can rebuild an MC30 yourself for approximately \$100 to \$120 in parts. I am going to walk you through the process and why you should do it.

You will see many MC30s advertised as “working, tech checked, etc.” You definitely want to buy a

working unit. Ones advertised “as is” or “untested” will most likely bring you little happiness and much expense. There is currently only one re-winder for these transformers in the US. There are a couple overseas re-winders, but the cost starts at about \$800 per transformer, not including shipping, which will bring your costs up to about \$1,000. I have no experience with the results of their work so I cannot comment on that.

You will occasionally see used MC30 outputs on eBay but the cost usually starts at about \$600. The output transformer contains the one major weakness in the MC, there is no protection of the unity coupling winding in the event of an output tube failure. If an output tube shorts, the plate to cathode current goes up through the unity winding. If it is not shut down promptly, it will open the winding. I will explain later in the article how to protect these “unobtainium” transformers during the rebuild.

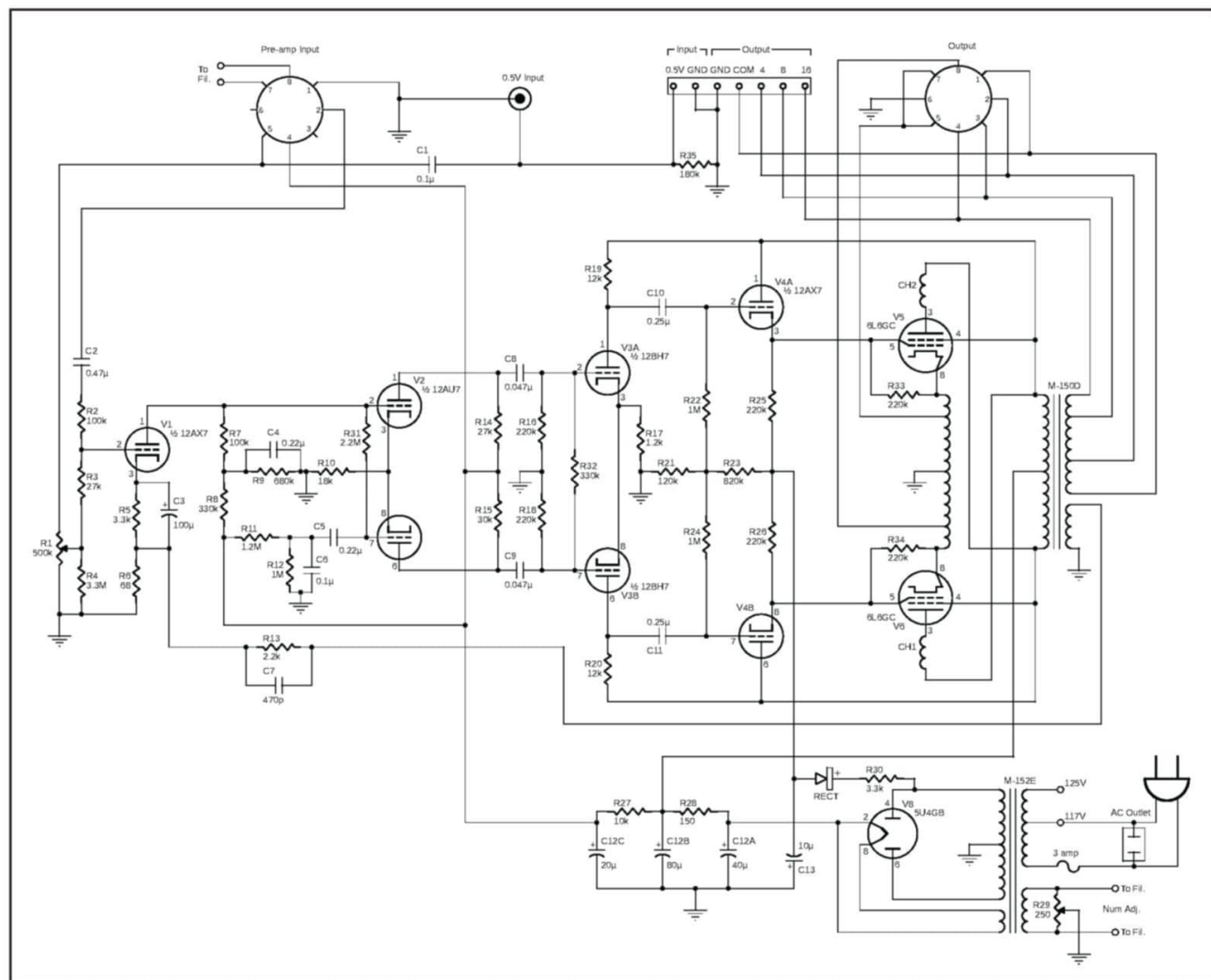


Figure 1b: This is a schematic of an earlier version of the MC30 showing different output and power supply details (for Serial #15329 and above).

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Figure 2: Cap board side of the tag board

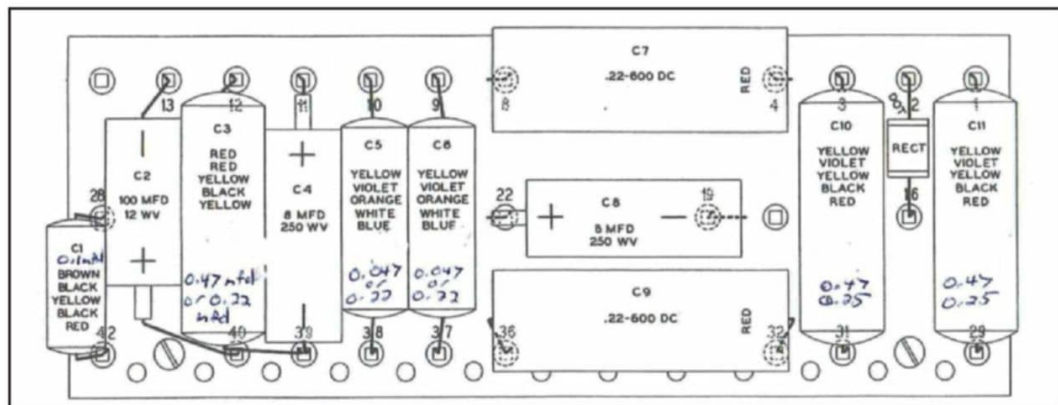
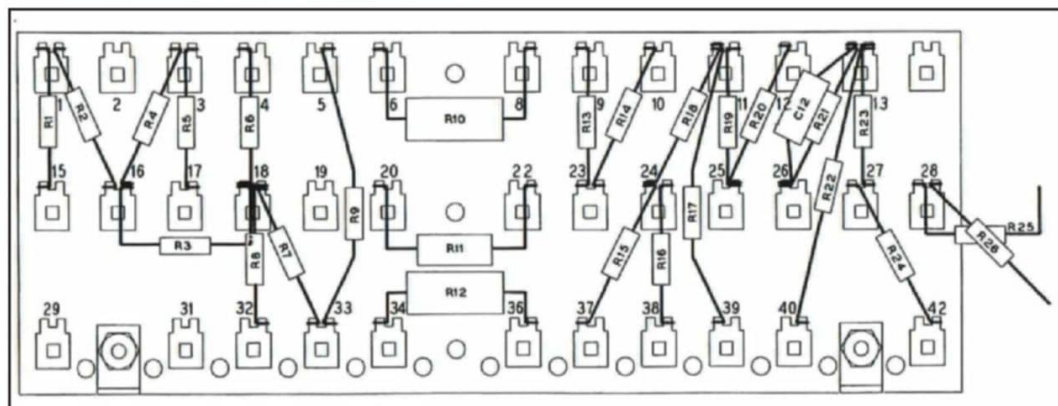


Figure 3: Resistor board side of the tag board



## Rebuilding the MC30

So what are we going to do during a rebuild? In my opinion we must complete the following list:

- Replace the filter can cap
- Replace all other electrolytic caps located on the tag board
- Replace the selenium bias rectifier with a silicon diode and dropping resistor
- Measure and replace any off value resistors
- Polish the chassis chrome
- Slightly lower power supply voltage to account for increased AC line voltage today vs. 1959

In addition, I will discuss some options to improve use and offer protection of the amplifier by:

- Adding a power switch without drilling any holes in the amplifier
- Increase the value of the filter and bias capacitance to improve performance
- Add a choke under the chassis to reduce the load on the filter caps and reduce hum
- Add an under chassis fuse to protect the output transformer from tube failure

A schematic is very helpful at this point, it you are lucky you might also find a copy of the McIntosh

instruction manual that gives you a chart of all of the DC and AC voltages and resistance values (with amp off) at the various tube pins. This can help you trouble shoot an amp that is not working correctly. Be aware that I have found at least four versions of the factory schematics as well as several SAMS schematics, so yours may not be exactly the same. Factory schematics are a little confusing in that they name and number components with different numbers from version to version. I am including illustrations from the MacKIT Assembly Manual,<sup>[3]</sup> as well as a schematic from an earlier version of the MC30, which are not for commercial use (see **Figures 1-3**).

The first step is to remove the tubes and bottom chassis cover. This is a good time to clean and polish the chassis and put some DeOxit on all the tube socket pins and shoot some in the volume and hum control. I use the spray for this and the concentrated stuff with the needle tip on the sockets. Cleaning the chassis and polishing it can be time consuming, but will greatly improve its appearance. I use a product called "The Intimidator," which is a mag wheel polish available at most automotive wheel stores. You can also order it on Amazon, eBay, or at [www.intimidatorpolish.com](http://www.intimidatorpolish.com). It can be used on aluminum, paint, gold, silver, copper, stainless chrome, and some plastics. It removes rust, glue, grime, and minor scratches. It is the best thing I have found to use on chrome and nickel-plated chassis.

It a green liquid you put on a soft cloth and rub in. Turn the cloth frequently and reapply, you will get lots of black and brown crud off the chassis, Use carefully on the silk screen, if you rub too hard you will remove it! When you have gone over the complete chassis let it dry and then buff with a terry cloth, you will be amazed!

You will see from **Photo 2** that the MC30 amp I restored had already had a few caps replaced. Inspect the tag board and resistors for signs of overheating and damage. Next measure the value of each of the resistors on the tag board and verify their values (see Figure 1, the schematic is very helpful here as you can see what the value should be with any other series resistors). Mark any that are off by more than 5% from marked value. You can also test each capacitor for value and leakage, if you have a good cap meter. My experience has shown that most of the "Bumble Bees" or "Black Beauties" will either be leaky or off value, so I replace all of them with axial lead film capacitors. There is nothing worse than replacing half the caps and then in six months having to go back and replace the other half. Do it once, do it right. We could get into a long, highly contentious discussion about caps. I use Illinois Capacitor or Solen polypropylene film caps. I have found these tend to

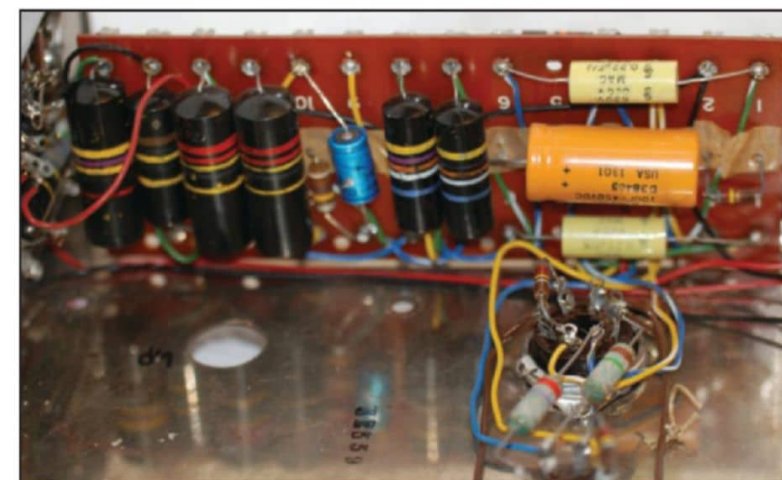


Photo 2: The MC30 amp that I restored had already had a few caps replaced.

## References

- [1] R. Russell, McIntosh, "McIntosh Amplifiers Part 1: A History," [www.roger-russell.com/amplif1.htm#mc30](http://www.roger-russell.com/amplif1.htm#mc30).
- [2, 3] MacKIT Assembly and Construction Manual, McIntosh Laboratory, Inc., 2 Chambers St. Binghamton, NY.

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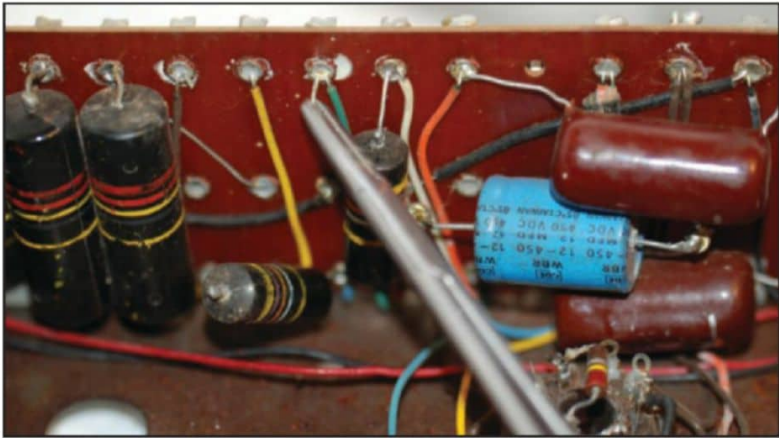


Photo 3: I have found the easiest way to replace the caps is to do it one at a time, cut the leads close to the cap body. Heat the lug on the other side of the tag board and push the lead through.

be the most neutral “sounding” caps. Some people like “orange drops” and others will use “boutique” caps. I have a hard time paying \$20 per cap, as do most of my customers. I have also used some Russian oil caps, but the issue generally with them is their overly large size. They do tend to be very mellow, for those who want a very relaxed sound. I have had a number of customers comment that their rebuilt amp is “cleaner, more defined, and sharper” than before. Remember that their amp had a number of leaky or off-value caps and they were not hearing the sound that amp had originally. I would really have liked to hear a new straight-out-of-the-box MC30.

The bottom line is use whatever caps you want to use, within reason. If you have a cap meter, I would recommend buying a small quantity of caps of each value and then match them where pairs are needed. I have found the easiest way to replace the caps is to do it one at a time, cut the leads close to the cap body. Heat the lug on the other side of the tag board and push the lead through (see **Photo 3**). My friend Patrick Brunner uses a Soldapult suction tool with a piece of silicon tubing on the end to remove solder, he swears by it. Use good needle nose pliers, or my favorite wire tool—a suture needle holder. (They are available online and really reasonably priced). This will loosen up the connection on the other side and make things easier to get off. **Be very careful**—the tag boards are fragile and the lugs break off easily. Some wires will come off easily and some are really tough. If one of the resistors you marked earlier goes to the same terminal, you can remove and replace it at the same time. Slide the new cap leads through the board and wrap them securely around the terminal. Make sure when you get to the electrolytic caps on the tag board you get the polarity right. The bias cap in most 30s is 10 mfd 450 V. I use 50 to 100 mfd at 450 V. The increased capacitance will benefit the bias circuit stability The rest of the bias system is a little strange and depends on the amplifier’s year of manufacture. The

MacKIT Parts List (see Figure 1a)

|                       |                                       |                                                 |                                                                                                                                              |
|-----------------------|---------------------------------------|-------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Capacitors</b>     |                                       | R5                                              | 56 kΩ                                                                                                                                        |
| C1                    | 0.1 mf, 200 V film cap                | R6                                              | 1 MΩ                                                                                                                                         |
| C2                    | 100 mf, 12 V electrolytic cap         | R7                                              | 56 kΩ                                                                                                                                        |
| C3                    | 0.22 mf, 600 V film cap               | R8                                              | 56 kΩ, 5%                                                                                                                                    |
| C4                    | 8 mf, 250 volt electrolytic cap       | R9                                              | 1.2 kΩ                                                                                                                                       |
| C5                    | 0.047 mf, 600 V film cap              | R10                                             | 12 kΩ, 2 W, matched to R12 to 1%                                                                                                             |
| C6                    | 0.047 mf, 600 V film cap              | R11                                             | 18 kΩ, 1 W                                                                                                                                   |
| C7                    | 0.22 mf, 600 V fim cap                | R12                                             | 12kΩ, 2 W                                                                                                                                    |
| C8                    | 8 mf, 250 V electrolytic cap          | R13                                             | 220 kΩ                                                                                                                                       |
| C9                    | 0.22 mf, 600 V film cap               | R14                                             | 220 kΩ                                                                                                                                       |
| C10                   | 0.47 mf, 600 V fim cap                | R15                                             | 30 kΩ, 5%                                                                                                                                    |
| C11                   | 0.47 mf, 600 V film cap               | R16                                             | 27 kΩ, 5%                                                                                                                                    |
| C12                   | 470 mmf (pico), 500 V silver mica cap | R17                                             | 680 kΩ                                                                                                                                       |
| C13a                  | 35 mf, 500 V can cap                  | R18                                             | 330 kΩ                                                                                                                                       |
| 13b                   | 8 mf, 450 V can cap                   | R19                                             | 100 kΩ                                                                                                                                       |
| 13c                   | 15 mf, 450 V can cap                  | R20                                             | 2.2 MΩ                                                                                                                                       |
|                       |                                       | R21                                             | 2.2 MΩ, 5%                                                                                                                                   |
|                       |                                       | R22                                             | 3.3 kΩ                                                                                                                                       |
| <b>Chokes</b>         |                                       | R23                                             | 68 Ω, 5%                                                                                                                                     |
| CH1                   | 1.5 μH choke                          | R24                                             | 1 MΩ                                                                                                                                         |
| CH2                   | 2.7 μH choke                          | R25                                             | 100 kΩ                                                                                                                                       |
|                       |                                       | R26                                             | 27 kΩ                                                                                                                                        |
| <b>Potentiometers</b> |                                       | R27                                             | 150 Ω, 10 W                                                                                                                                  |
| POT 1                 | 200 Ω linear taper pot                | R28                                             | 10 kΩ, 10 W                                                                                                                                  |
| POT 2                 | 250 kΩ audio taper pot                | R29                                             | 330 kΩ                                                                                                                                       |
|                       |                                       | R30                                             | (Not on schematic but with silicon diode replacment of selenium rectifier will be 3.3 kΩ to 5.6 kΩ, will be determined in Part 2 of article) |
| <b>Resistors</b>      |                                       | **Note all resistors are 0.5 W unless specified |                                                                                                                                              |
| R1                    | 56kΩ                                  |                                                 |                                                                                                                                              |
| R2                    | 56 kΩ                                 |                                                 |                                                                                                                                              |
| R3                    | 100 kΩ, 5%                            |                                                 |                                                                                                                                              |
| R4                    | 56 kΩ                                 |                                                 |                                                                                                                                              |

selenium rectifier might be a little gray square about a 1/4” thick mounted on the cap side of the board or it might be a long brown cylinder on the resistor side of the board. Either way, these are selenium rectifiers and must be replaced. As they age, they have much more voltage drop and this decrease in negative bias voltage makes the output tubes run hotter and might even take out the output transformer. Some McIntosh’s have a dropping resistor in the line from the 5U4 pin 4 to provide bias voltage from the high-voltage side of the transformer, and some have a separate bias tap off the transformer that runs directly to the diode. You will be selecting a resistor either way to get the bias voltage to the 12AX7 and 6L6s at -41 V to -45 V. More on this later. You can see in **Photo 4** that I elected to attach a small terminal strip in the place of the gray rectifier and have mount the new silicon diode (1N4007) to the strip and temporarily tacked a resistor between the AC from the transformer and the positive side of the silicon diode.

**Next Month**

In the second part of this two-part article, we replace the can cap on the top of the chassis, rewire the rectifier tube socket, and check the wiring before doing the final checks and measurements. We will also address some improvements and protection for the MC30s.

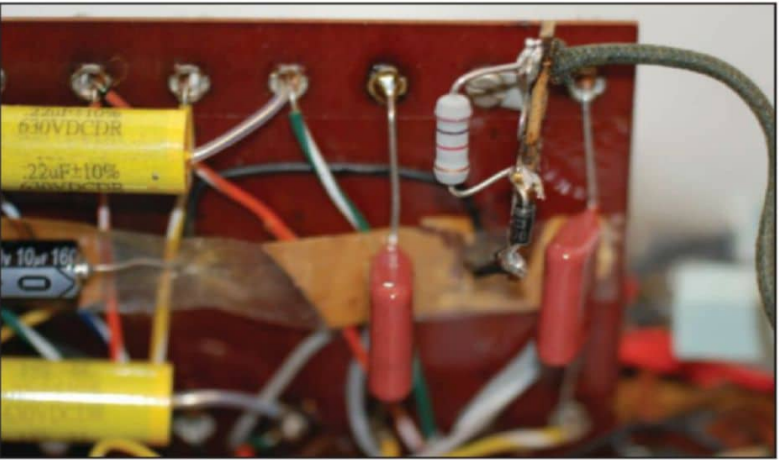


Photo 4: I elected to attach a small terminal strip in the place of the gray rectifier and have mount the new silicon diode (1N4007) to the strip and temporarily tacked a resistor between the AC from the transformer and the positive side of the silicon diode.

About the Author

Bruce W. Brown has been experimenting with electronics and building stuff since the 1960s. He started his own business at age 15, installing house intercom and stereo system sand building Heathkit and Dynaco stereo amps for sale to friends and family (or anyone who wanted to buy one) He worked repairing stereo equipment for an audio store during his years in Pharmacy School. He has been a long time tube amplifier builder and restorer as well a contributor to *Glass Audio* and *audioXpress*. He restores tube amplifiers, as well as constructs custom amplifiers at his business Vintage Tube Audio (Vintagetubeaudio.com). He is happy to reply to questions at Tuninfork@aol.com.

Earlier MC30 Parts List (see Figure 1b)

| Capacitors |                                       | R9                                                     | 680 kΩ                                                                      |
|------------|---------------------------------------|--------------------------------------------------------|-----------------------------------------------------------------------------|
| C1         | 0.1 mf, 400 V film cap                | R10                                                    | 18 kΩ, 1 W                                                                  |
| C2         | 0.47 mf, 200 V film cap               | R11                                                    | 1.2 MΩ                                                                      |
| C3         | 100 mf, 12 V electrolytic             | R12                                                    | 1 MΩ                                                                        |
| C4         | 0.22 mf, 400 V film cap               | R13                                                    | 2.2 kΩ, 5%                                                                  |
| C5         | 0.22 mf, 400 V film cap               | R14                                                    | 27 kΩ, 5%                                                                   |
| C6         | 0.1 mf, 400 V film cap                | R15                                                    | 30 kΩ, 5%                                                                   |
| C7         | 470 mmf (pico), 500 V silver mica cap | R16                                                    | 220 kΩ                                                                      |
| C8         | 0.047 mf, 600 V film cap              | R17                                                    | 1.2 kΩ                                                                      |
| C9         | 0.047 mf, 600 V film cap              | R18                                                    | 220 kΩ                                                                      |
| C10        | 0.25 mf, 600 V film cap               | R19                                                    | 12 kΩ, 2 W matched 1% to R20                                                |
| C11        | 0.25 mf, 600 V film cap               | R20                                                    | 12 kΩ, 2 W                                                                  |
| C12        | 10 mf, 450 V electrolytic             | R21                                                    | 120 kΩ, 5%                                                                  |
| C13a       | 40 mf, 500 V Can cap                  | R22                                                    | 1 MΩ                                                                        |
| C13b       | 80 mf, 450 V Can cap                  | R23                                                    | 820 kΩ, 5%                                                                  |
| C13c       | 10 mf, 450 V Can cap                  | R24                                                    | 1 MΩ                                                                        |
| Chokes     |                                       | R25                                                    | 220 kΩ                                                                      |
| CH1        | 1.5 mH choke                          | R26                                                    | 220 kΩ                                                                      |
| CH2        | 2.7 mH choke                          | R27                                                    | 10 kΩ, 10 W                                                                 |
| Resistors  |                                       | R28                                                    | 150 Ω, 10 W                                                                 |
| R1         | 500 kΩ audio taper pot                | R29                                                    | 250 Ω linear taper pot                                                      |
| R2         | 100 kΩ                                | R30                                                    | 3.3 kΩ (we will determine the new value after replacing selenium rectifier) |
| R3         | 27 kΩ                                 | R31                                                    | 2.2 MΩ                                                                      |
| R4         | 3.3 MΩ                                | R32                                                    | 330 kΩ                                                                      |
| R5         | 3.3 kΩ                                | R33                                                    | 220 kΩ                                                                      |
| R6         | 68 Ω, 5%                              | R34                                                    | 220 kΩ                                                                      |
| R7         | 100 kΩ                                | R35                                                    | 180 kΩ                                                                      |
| R8         | 330 kΩ                                | ***All resistors are 0.5 W unless otherwise specified. |                                                                             |



# A Second Life for a Vintage Tube Amplifier

Just for fun, Mark Driedger decided to revamp his old Electra EL-3000. Maybe this article will inspire others to revisit some of their past projects.



Photo 1: Here is a photo of the original Electra EL-3000 amplifier (photo circa 1980).

By  
**Mark Driedger**  
(United States)

I am a pack rat. There, I admitted it. I have the first tax return I ever filed and that transformer from the oscilloscope I ripped apart in 1980. One of the treasures that I lugged around for 25 years and seven household moves is a nice little Japanese tube amplifier. The nameplate says it is an Electra EL-3000 (see **Photo 1**). I have never been able to find a reference for that model; however, it is virtually identical to the Herald AM-10A and the Olson AM-158.

Olson was a US retailer that owned the Herald brand and imported both from Japan. I suspect the Electra is another rebranding of the same amp. It uses a pair of 6BM8 in each channel for the power amp, is well made, and has some nice looking (if modest) iron. At some point in high school, I removed the phono stage and made some modifications to the power amp. The amplifier had fallen into disuse and no longer passed the living room decorating test.

## The Electra's First Life

The 6BM8 (ECL82 in Europe) first showed up in the *RCA Tube Manual* in 1964 (RC-23), but seems to have been in use from the late 1950s. Quite a few amplifiers of that era used the 6BM8, especially

where small size was a factor. Typical examples are the Knight KG-250 and the Realistic SAF-24D (integrated amplifiers) and the Sansui 500 and the Pioneer XS-34 (receivers). It also saw a lot of use as a single-ended amplifier in radios, TVs, reel-to-reel tape recorders, and phonographs (driver and output stage in one bottle). The Russian 6F3P (6Φ3П) is equivalent and quite inexpensive from multiple sources on eBay. The 11BM8, the PCL82, and the 50BM8/UCL82 are identical except for filament voltage.

The 6BM8 is a 9-pin dual section miniature tube containing a high  $\mu$  ( $\mu = 70$ ) triode and a pentode power section with 7 W plate dissipation rating. A pair of 6BM8 pentodes in push pull will produce about 8 W, and you can build a complete power amp with only two tubes per channel. The most common configuration for the input section is a split load phase inverter direct coupled to the input stage and capacitively coupled to the push-pull fixed bias output stage.

## Its Second Life

I decided to give the Electra a second life by rebuilding it from my hand-drawn schematic of the original and reusing the iron (power and output

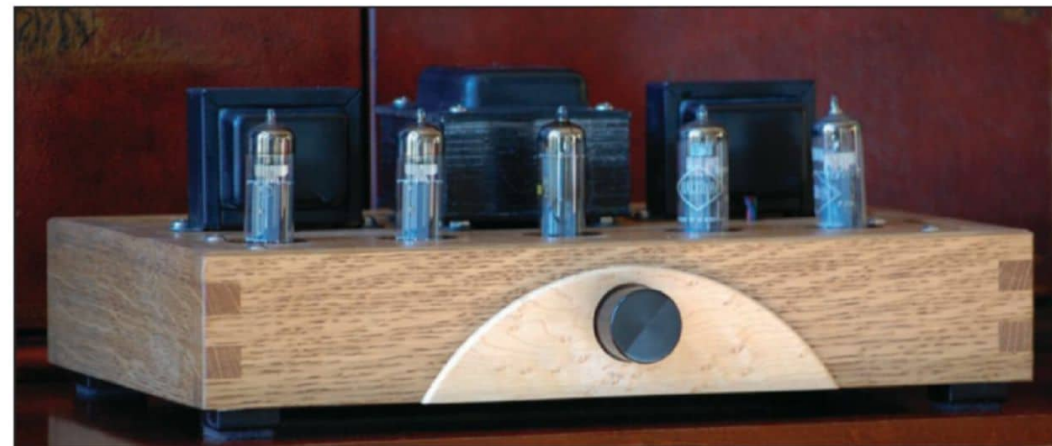


Photo 2: Here is the new 6BM8 amplifier.

transformers). The Japanese transformers from that era are highly regarded. A wooden chassis showcases the tubes and iron (see **Photo 2**). I built the amp for use with a CD player or USB DAC source and included a volume control but no input switching.

The original used point-to-point construction. However, I decided to build the amplifier and the power supply circuitry on a turret board. Turret boards most often house passive components and are wired to tube sockets mounted on a metal chassis, as in most guitar amplifiers. In this case, I mounted the tubes to the turret board as well. The complete circuit can then be built and tested before installing in the chassis.

The amplifier is quite simple (see **Figure 1**). The first stage is a common triode voltage amplifier using half of one 6BM8 (V1A). The input is capacitor coupled into the stereo volume control (R100) and then to the grid of the common cathode amplifier. This stage runs at a bias current of 0.7 mA and the cathode resistor, R103, is un-bypassed to facilitate feedback from the output.

The first stage plate output is direct coupled to a split load phase inverter (V2A). It is biased at 0.8 mA and produces complementary copies of the input signal (gain is roughly  $\pm 1$  to each output). The phase inverter outputs are AC coupled to the 6BM8 pentode push pull output stage. Resistors R108 and

R109 are grid stoppers and reduce the chance for oscillation and RFI coupling.

Fixed bias is established for the push-pull pair by R110 and C105. I used a bias of 25 mA per tube. You can experiment with the bias point by adjusting R110 between about 300 and 500  $\Omega$ . Bias current per tube is  $\frac{1}{2} \times V_{\text{bias}}/R_{110}$ , where  $V_{\text{bias}}$  is the voltage across R110, and should not exceed 40 mA. Negative feedback is taken from the output transformer back to the first stage cathode.

The Electra power supply (see **Figure 2**) uses a 6CA4 rectifier in a center tap full-wave configuration. A separate isolated 6.3 V/1 A filament winding heats the rectifier. Initially I had some hum problems, which I traced to ripple on the screen grid supply. After adding some extra decoupling on the screen grids (R200 and C201) the problem cleared up.

The B+ supply provides 285 V to the output stage from an inductor input filter. Originally, the amplifier had a capacitor input filter. However, the B+ voltage was too high so I added the inductor to lower the voltage and to reduce ripple.

The screen grids are fed from a second RC filter stage. Each channel of the input/splitter stage has a separate decoupling RC stage and drops the voltage to 240 V. If you experience excessive hum, then you can reference point B (output stage cathode) on one

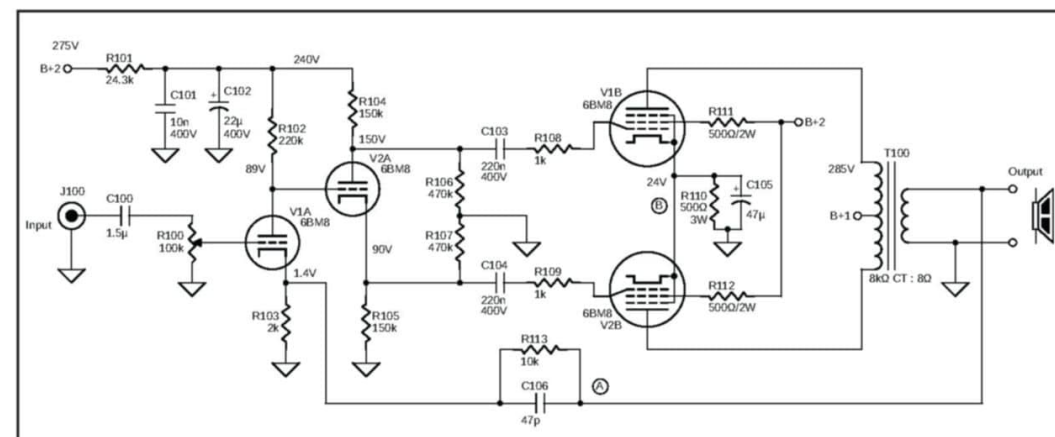


Figure 1: I used this schematic to build the amplifier (one channel is shown).



Figure 2: Here is the power supply schematic.

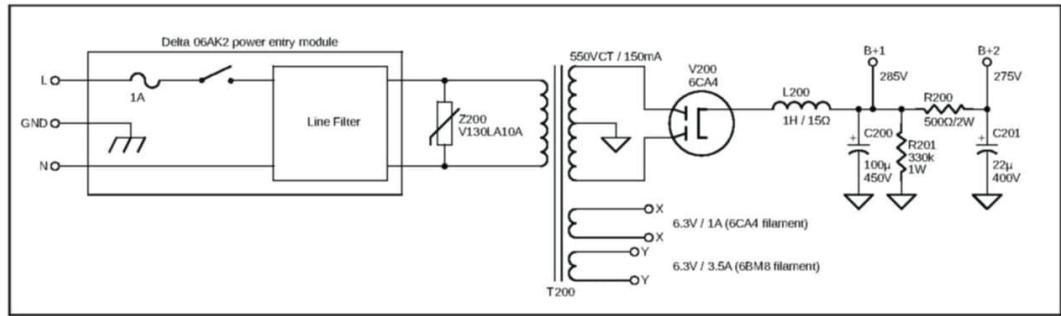


Photo 3: The rear view of the amplifier shows input, output, and power connections.

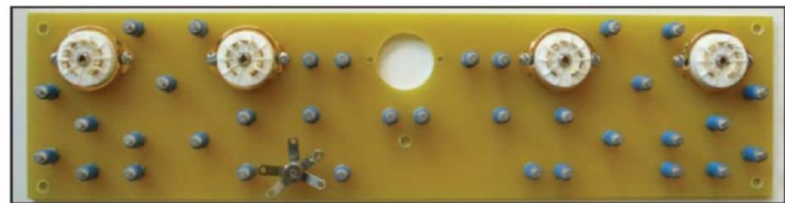


Photo 4: This image shows the blank turret board.

### Parts List for the Amplifier (One Channel)

| Capacitors    |                                                 |
|---------------|-------------------------------------------------|
| C100          | 1.5 $\mu$ F, film (Ero MKC1863)                 |
| C101          | 10 nF, 400 V orange drop                        |
| C102          | 22 $\mu$ F, 400 V electrolytic                  |
| C103, C104    | 22 nF, 400 V film (Ero KT1801)                  |
| C105          | 47 $\mu$ F, 50 V electrolytic                   |
| C106          | 47 pF, mica                                     |
| Miscellaneous |                                                 |
| J100          | RCA input jack<br>Speaker terminals             |
| Resistors     |                                                 |
| R100          | 100 k $\Omega$ audio taper stereo potentiometer |
| R101          | 24 k $\Omega$ , 1 W                             |
| R102          | 220 k $\Omega$ , 1 W                            |
| R103          | 2 k $\Omega$ , 0.5 W                            |
| R104, R105    | 150 k $\Omega$ , 1 W                            |
| R106, R107    | 470 k $\Omega$ , 0.5 W                          |
| R108, R109    | 1 k $\Omega$ , 0.5 W                            |
| R110          | 500 $\Omega$ , 3 W                              |
| R111, R112    | 500 $\Omega$ , 2 W                              |
| Transformer   |                                                 |
| T100          | Hammond 1608, 1609, or similar                  |

Table 1: This is the parts list for one channel of the amplifier.

of the channels to one side of the 6BM8 filament (Y).

The transformers were reused from the original amplifier. You may be able to find an Olson amplifier to use as a donor for the transformers. If not, a Hammond 1608 or 1609 can be used as replacements for the output transformer or you can search eBay for a similar one (8 to 10 k $\Omega$  center tapped primary, 8 to 10 W, 30 to 40 mA DC current). If the transformers are mounted out of harm's way (inside a chassis or cabinet) the open-frame-style Hammond 125D is another option.

The closest substitutes I could find for the power transformer is a Hammond 270EX or 270FX. Their rectifier filament windings are 5 V, not 6.3 V. If you can't find a better substitute, then the simplest option is to add a separate 6.3 V/1 A transformer such as the Hammond 166J6 to power the 6CA4 filament. The choke came from my junk bin and measures about 1 H and 15  $\Omega$  series resistance. A Hammond 157R is close (2 H, 57  $\Omega$ , 200 mA).

### Construction

Remember that tube circuits use hazardous voltages. Turn the power off and fully discharge all capacitors before touching any of the circuitry. If you are not confident about working safely with tubes and high voltages, then do not attempt this build.

The wooden chassis worked out well. Be careful to provide adequate clearance around the tubes and airflow for cooling if you take the same approach. Use spacers between the power transformer and the chassis to reduce some of the heat transfer. The cabinet is oak, with the sides joined using a box joint. I reused the perforated bottom plate from the Electra and openings in the chassis for airflow. Since there are no low level signals in the amplifier, the lack of shielding was not an issue. Just use shielded cable on the inputs. The amplifier is quite compact—measuring 10"  $\times$  14"  $\times$  6". A power entry module in the rear provides line filtering, switching and fusing. RCA input jacks and bindings posts are mounted at the rear as shown in **Photo 3**.

Everything except the volume control, transformers, and connectors are located on a turret

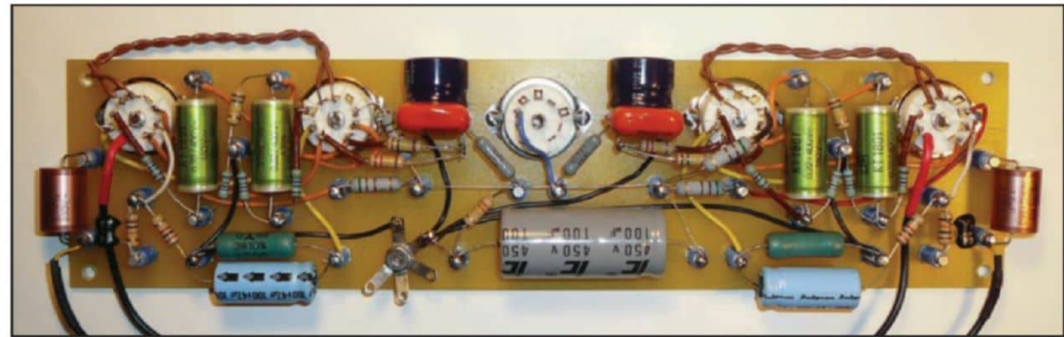


Photo 5: Here is my completed turret board.

board made of 3"  $\times$  12"  $\times$  1/8" thick Garolite or FR4 material. This is the same material PCBs are made of, but a lot thicker and with no copper. McMaster-Carr is a good source for Garolite and other plastics, hardware, and metal stock. I had a stash of insulated turrets that attach with 4-40 screws. You can use less expensive swage turrets. There is a good tutorial on making turret boards on the Guitar Kit Builder website.

The Garolite is thick enough that it can be threaded using a normal metal tap to fasten the tube sockets, and to attach the turret board to the chassis. Since Garolite contains fiberglass, wear a dust mask and gloves when cutting or filing it and wear long sleeves as the dust can irritate the skin. The holes for the tube sockets can be drilled with a bimetal hole saw. The turret board is shown in **Photo 4** (blank) and **Photo 5** (populated). I used stainless machine bolts to secure it to the chassis in a nod to the original Electra, which amazingly used stainless hardware everywhere, each nut carefully secured with thread lock. The parts lists are detailed in **Table 1** (amplifier, one channel) and **Table 2** (power supply).

Leave the feedback path open initially—don't connect point A to the output transformer secondary. After checking your build and powering up the amplifier, measure the DC voltages and compare them against the schematics. For safety, connect the negative voltmeter lead to ground with an alligator clip while the power is off. Then probe using one hand to measure voltages. This reduces the chance of having a high voltage span your hands (and heart). If the output stage bias voltage is too high or low, then you can adjust R110 to give the right bias current.

With an old speaker and input source connected, power up the amp. Then close the feedback loop by connecting point A to the output transformer secondary. If you have the phasing right, the volume should drop relative to the open loop case. An increase in volume or oscillation means you need to unplug the amp, discharge all capacitors and then swap the output transformer leads to the output tube plates.

### The Results

I use the amplifier with a pair of reasonably efficient PSB 500i speakers and a USB DAC. For

normal listening, it has more than enough volume and sounds pretty good considering it is just two 9-pin miniature tubes per side. It sounds particularly good with acoustic music and vocals—a bit under-matched compared to a bigger amp on more complex sources. I tried the Haltron tubes from the original EL-3000 (yes, I still have those after 25 years) and some 6F3P Svetlanas that I bought on eBay.

Overall, I'm very pleased with the result. Now I just need to figure out what to do with the chassis and other parts from the original EL-3000 ... maybe in another 25 years. ☹️

### Parts List for the Power Supply

#### Power Entry Module (Delta 06AK2 or similar)

| Capacitors  |                                                  |
|-------------|--------------------------------------------------|
| C200        | 100 $\mu$ F, 450 V electrolytic                  |
| C301        | 22 $\mu$ F, 400 electrolytic                     |
| Choke       |                                                  |
| L100        | 1 H, 15 $\Omega$ series resistance, 150 mA choke |
| Resistors   |                                                  |
| R200        | 500 $\Omega$ , 2 W                               |
| R201        | 300 k $\Omega$ , 1 W                             |
| Transformer |                                                  |
| T200        | Power Transformer (see article)                  |
| Varistor    |                                                  |
| X100        | MOV, V130LA10A                                   |

Table 2: Here is the parts list for the power supply.

### About the Author

Mark Driedger has been experimenting with tube audio since 1980. He completed an MSc in electrical engineering at the University of Waterloo, Canada, and has worked in the telecom industry for more than 30 years in technical and executive roles. His other passions include woodworking, the guitar, and spending time with his wife, children, and grandchildren.

### Resources

"Basic Turret Board Construction," Guitar Kit Builder, March 2011, <http://guitarkitbuilder.com/basic-turret-board-construction>.



# Build a Budget-Friendly High-Performance Valve Headphone Amplifier

Learn how to build a valve headphone amplifier with only six components in the active circuit portion (per channel). There are no capacitors, it is easy to configure, and sounds very nice. How can that be? Well, it required a hard look at what a headphone amplifier really needed to do.

By  
**Bruce Heran**  
(Oddwatt Audio)

Before I built my headphone amplifier, I wanted to figure out its purpose. Obviously it had to have some gain, some power output, low distortion, wide response, and especially low noise. It needed to provide a modest power output and match the impedance of a majority of common headphones (see **Photo 1**).

Now for those of you who have jumped to the schematic (see **Figure 1**), yes it is a variation of

something I dreamed up nearly a decade ago. When something works well, it stands the test of time. This is one of those projects. What I have found over time is that the original power supply and configuration (see **Photo 2**), while very good, it could be improved a bit.

## The SMPS

Recently I revisited the amplifier and did what most DIYers do, I tinkered with it. I found that I could make it easier to build and cheaper using a solid-state switching mode power supply (SMPS). These SMPSs are dirt cheap and quite excellent for powering low power demand gear. Since the amplifier needs less than 100 mA of current and pretty much any voltage between 100 V and 150 VDC will work, an adjustable SMPS is a natural. I found three that work great. There are certainly others and you can “roll” your own if desired. The one I chose costs about \$5 US (see **Photo 3**).

It actually has both positive and negative outputs, but you don’t need to use the negative side. There is a companion single positive output version that is identical except they leave out a few parts. Funny thing is it costs more. Less parts equals higher cost in this case. Both versions are able to produce up to 450 VDC

with an output of up to 40 W. I suspect that 40 W is a bit optimistic. They do, however, easily deliver the 100 mA needed at the 125 V to 150 V range. The only power supply components I added for the B+ were a small choke and an electrolytic filter capacitor. I like my gear, especially headphone amplifiers, to be really, really quiet. In this case, the wideband signal-to-noise ratio (SNR) is -85 dB (see **Figure 2**).

The input for the SMPS is 12 VDC. I used an external “brick” rated at 5 A to power both the SMPS and tube heaters. This avoids having any AC sources inside the amplifier and really simplifies the build.

## The Circuit

The circuit is a Class “A” push-pull self-inverting amplifier. The basic configuration has been around for a long time. However, it was always plagued by problems getting symmetrical drive to the second tube. An IC constant current source (LM317) in the cathodes solves the balance problem quite well. The output is transformer coupled to the headphones. This is where you can tailor the amplifier to your needs.

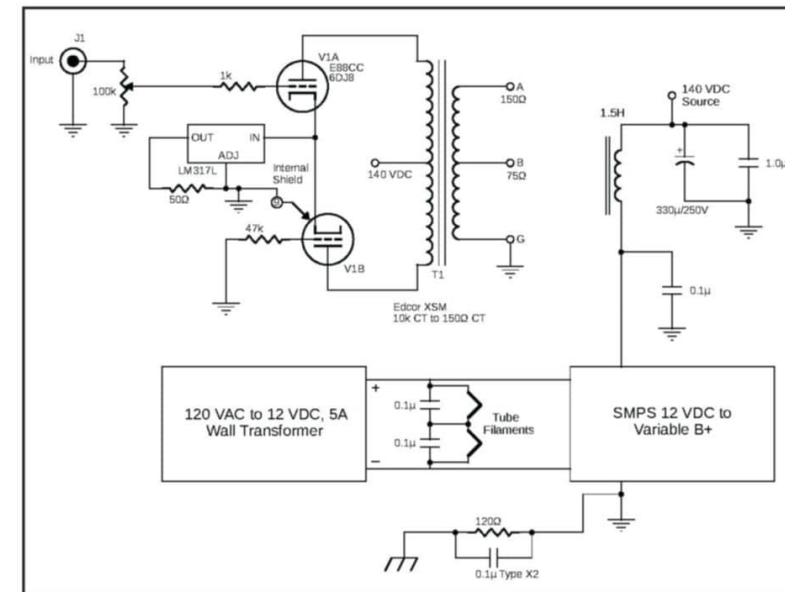


Figure 1: This schematic updates a design that I first dreamed up about 10 years ago.

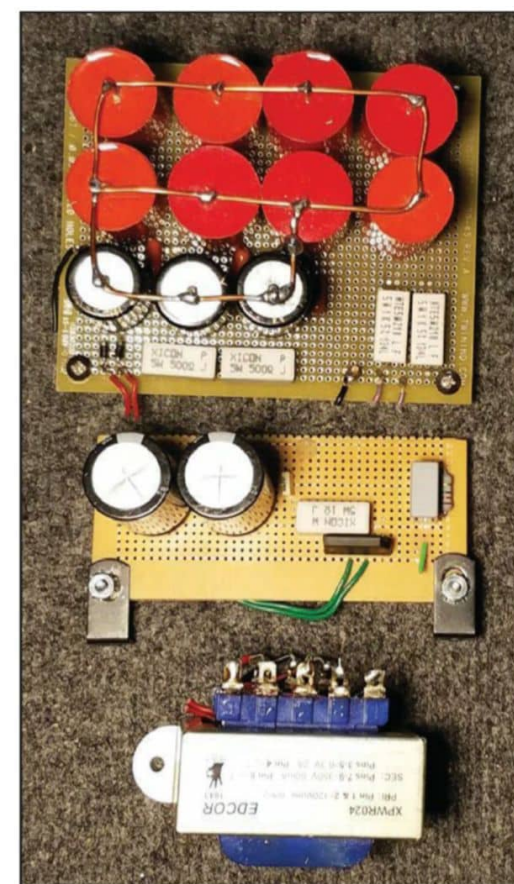


Photo 2: This is the original power supply and configuration for a design I dreamed up about 10 years ago.

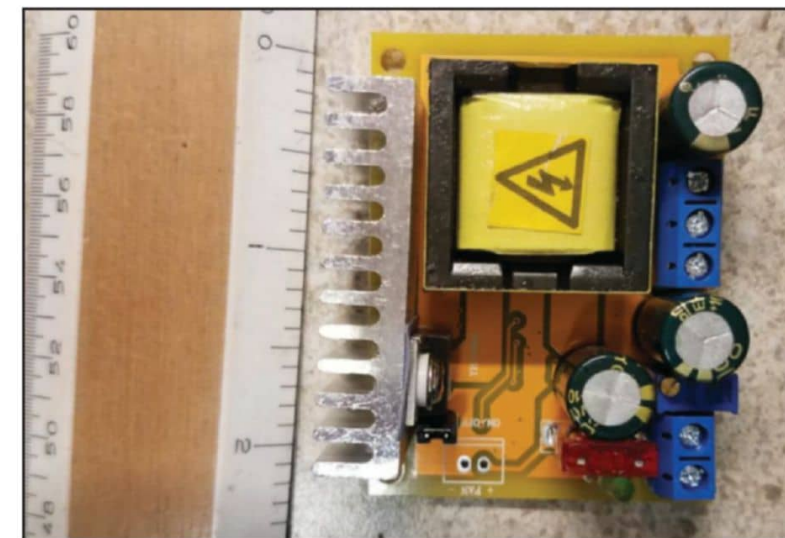


Photo 3: I could make it easier to build and cheaper using a solid-state switching mode power supply (SMPS). The one I chose was a little more than \$5.

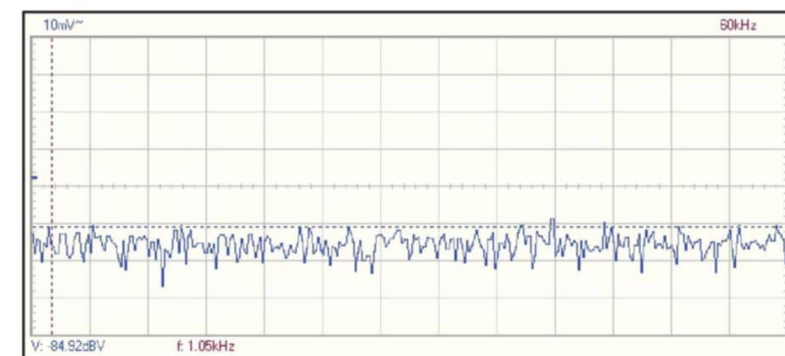


Figure 2: I tested the signal-to-noise level with zero input signal.



Photo 1: I only used six components in the active circuit to build this high-performance valve headphone amplifier.



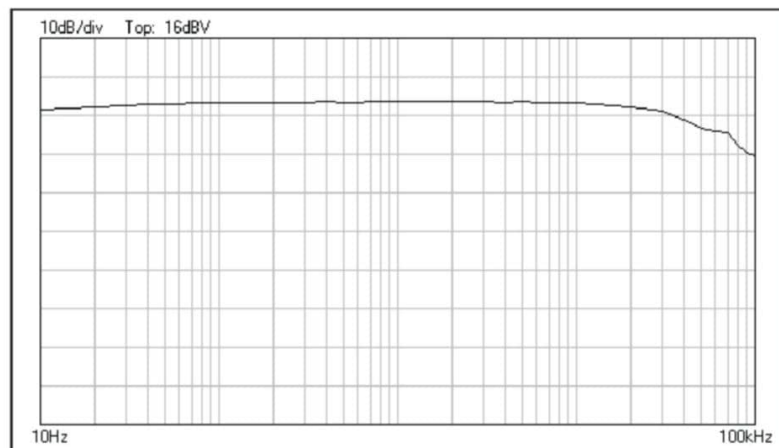


Figure 3: I measured a response range of 20 Hz to 20 kHz with the extremes down approximately 1 dB. At the -2 dB level, the frequency range was 10 Hz and 28 kHz.



Photo 4: This is the preamplifier with the shields removed.

## Components

- 1 AC Line voltage to 12 VDC "Brick" with output of approximately 5 A
- 1 12 VDC to variable high voltage DC switching mode power converter (I found three available online via Amazon and eBay)
- 2 6DJ8/E88CC tubes
- 2 10 k $\Omega$  push pull to needed impedance transformers
- Stereo volume control 100 k $\Omega$
- 2 LM317 (any variety) IC regulator
- 1 Electrolytic filter capacitor 330  $\mu$ F/250 VDC
- 1 Capacitor poly-type 1  $\mu$ F/250 VDC rating
- 1 Filter choke any value over 1.5 H, able to handle about 100 mA
- 2 Resistor 50  $\Omega$  0.5 W 5% tolerance
- 2 Resistor 47 k $\Omega$  0.5 W 5% tolerance
- 1 Type X2 capacitor 0.1  $\mu$ F (typical voltage is 250 to 275 VDC)
- 1 Capacitor Poly 0.1  $\mu$ F 350 VDC or higher
- 1 Resistor 1 W, 120  $\Omega$  any tolerance
- 2 Capacitor ceramic or poly-type 0.1  $\mu$ F 25 VDC or more rating
- 1 Indicator LED with series resistor suitable for 12 VDC operation (optional)
- Miscellaneous hardware, sockets, case, input and output jacks, and power switch

I used inexpensive matching transformers, but in reality many transformers will work. The tubes work well with an anode-to-anode load of around 10 k $\Omega$  in this circuit. Values as low as 8 k $\Omega$  or as high as 12 k $\Omega$  will not make a significant difference. The parameters that matter are the output impedance to match your headphones and the ability of the transformers to handle the DC current. Ones in the 0.5 W to 5 W range are usually fine. The ones I used are rated at 0.5 W. The transformer should have a wide bandwidth as well, otherwise the quality of the sound will suffer. If you skimp on this, the end result will most likely be very mediocre sound.

The voltage gain of the amplifier is about 0.9 with a 62  $\Omega$  load. It will deliver 50 mW into that load easily with about 3 V drive. This seems like a minute amount of power, however, remember that a large number of headphones can deliver about 100 dB sound pressure level (SPL) at around 1 mW. So, 50 mW will often be an ear damaging level. I measured a response range of 20 Hz to 20 kHz with the extremes down approximately 1 dB. At the -2 dB level, the frequency range was 10 Hz and 28 kHz (see **Figure 3**).

## The Build

The actual build is straight forward. As always, care is required as the voltages involved can be lethal. Wiring can be point to point, perforated board, or turret boards. All of them work fine for this project. I suggest using a metal enclosure that is ventilated to allow heat passage, but the choice of case material it is not really essential. The photos show the amplifier without internal shields (see **Photo 4**) and with the internal shields (see **Photo 5**).

They really are not necessary, but I like the way they look. The tubes, however, can pick up electromagnetic interference (EMI). If you do not use a full metal enclosure, then I would consider using tube shields.

In audio project builds, it is generally necessary to isolate the chassis from the input and output grounds. There are two reasons. First, it goes a long way in preventing ground loop based hum. Second, and in many ways more important, is that many electrical codes require that all external metal parts be connected to the AC mains ground (earth) or isolated from it. Using the "brick" handles this chore nicely as the actual chassis is completely isolated from the AC mains. Check the specifications on the one you acquire to insure that this is the case.

Incidentally, the amplifier will run on any 12 VDC source and likely be useable in a vehicle (not for the driver though) or powered by a battery of sufficient capacity. The tubes run fairly hot and need to have adequate ventilation. I used screw terminals in the build. They allow for easy board removal for modifications

and trouble shooting. It is not obvious in the photos but the LM317s are on a small perforated board between the tube sockets. They do not require extra ventilation. The chassis, the wood case, and the tube brackets were salvaged from earlier defunct projects. I frequently recycle such components and highly recommend the concept.

## The Listening Test

What does it sound like? I use mine with Sennheiser and Koss headphones and I find the sound full bodied, clear, and detailed with a very quiet background. The biggest drawback with the amplifier is the need for a signal source with enough output to overcome the lack of gain. I use a Fiio X3 and it is quite adequate. However, some low output devices (e.g., some cell phones) might not work well with the amplifier.

## About the Author

Bruce Heran lives in Sierra Vista, AZ, and is an avid DIYer. He has been involved in electronics for 59 years. He built his first project—a one-transistor amplifier—when he was 13. He has a BS in Biology and studied electrical engineering for two years. Electronics has always been his hobby. In May 2011, he retired from his work as a project manager of a logistics contract with the Federal government. Now he is co-owner of Oddwatt Audio, an electronics company that specializes in vacuum-tube audio components. He is vice president of design and support, and all of the company's products are kits and assembled audio equipment based on his personal designs. He is an avid collector of vinyl records and vintage turntables.

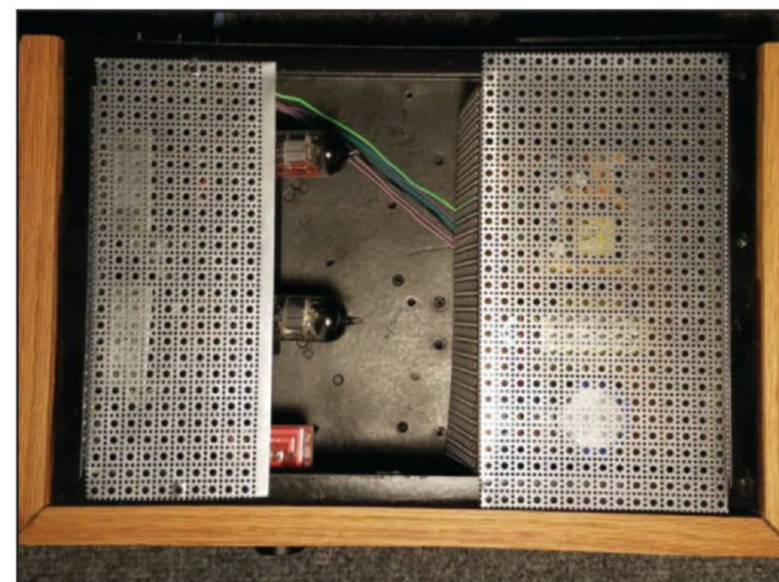


Photo 5: Here is the preamplifier with shields installed.

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# Desktop Vacuum Tube Headphone Amplifier

When *audioXpress* issued the call for vacuum tube projects, Bill Reeve decided to share one of his longtime favorite designs—a vacuum-tube based headphone amplifier that could also be used to drive small desktop speakers.



Photo 1: The front view of the preamp has two switches one for "Power" and the other for "Speaker Mute". The front cable is the output headphone jack, and the rear cable is incoming power. The googly eyes were later added to the volume and balance knobs by its owner.

Some years ago, I designed and built a low-voltage, stereo headphone driver for an audiophile friend of my youngest daughter. Both are software engineers in San Francisco, CA. Her friend requested a vacuum tube-based headphone amplifier that could also drive small desktop speakers. It needed to be both reliable and safe. This preamp has been in operation since the spring of 2011 (see **Photo 1**).

## Development Process

Initially, I sketched a functional block diagram of the entire amplifier on paper to ensure I had a complete design. It took about three iterations to get to the final version. Then I sketched out each block's circuit diagram on paper, going through three or four iterations, while performing circuit analyses of each section by hand. This ensured that each part of the design would function properly and have adequate margins with respect to current, voltage and power dissipation. Then, I built and tested separate breadboard prototypes of each circuit section to verify

the analysis and look for simplifications or oversights.

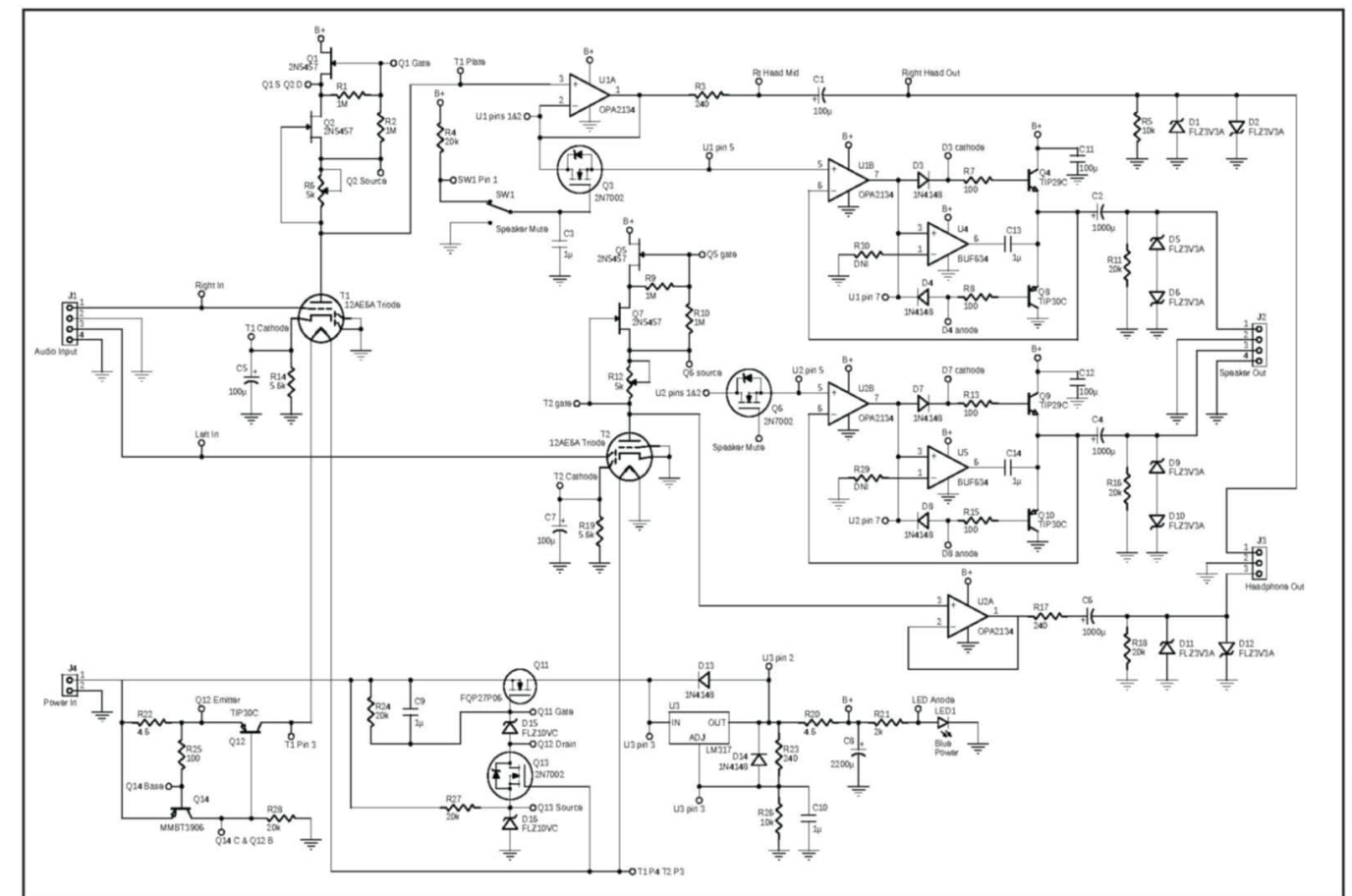
It was at that point that I put the circuit (see **Figure 1**) into schematic capture software and laid out a two-layer PCB. Performing thorough analysis, prototyping, netlist, and pad-pattern checks before going to layout resulted in the board functioning properly. The circuit has some notable features.

## Low-Voltage Vacuum Tube Preamplifier

The common-cathode pre-amplifier stage uses readily-available, low-voltage space-charge triodes (12AE6-A) that were originally developed in the 1950s for use in automobile 12 VDC radios. This allowed me to use a plug-into-the-wall 30 V, 1 A AC-to-DC converter, which keeps high voltages away from the circuit itself. This particular power supply was originally the power supply for a desktop printer. This voltage converter, combined with voltage regulator U3, results in a quiet B+ voltage. The vacuum tubes are biased by simple JFET current sources that can be trimmed (using R6 or R12) to set each tube in the middle of its operating range.

## Tube Heater Driver

The vacuum tube heater filaments are driven in series by a simple, uncompensated bipolar transistor constant-current source (Q12 and Q14). This increases tube life by eliminating turn-on inrush current that is characteristic of a constant-voltage design. I described this technique in my article "Constant Current for Tube Heaters," which ran in the May 2014 issue of *audioXpress*.



When the tubes are warmed up (this is sensed by Q13), the B+ supply is automatically switched on (through transistor switch Q11), and LED1 lights (indicating that the amplifier is ready).

## Output Stage

Each headphone output is driven directly by an operational amplifier (U1A and U2A), in this case a high-precision OPA2134. Each speaker driver is a simple bipolar transistor push-pull stage within the feedback loop of another dedicated op-amp (U1B and U2B). Placing a current buffer (U4 and U5, BUF634s) in parallel with the output transistors, and inside the op-amp's feedback loop, minimizes crossover distortion as the signal switches from one transistor to the other. Zener diodes protect all the outputs.

## Mechanical Assembly

A bespoke amplifier should show off its electronics, so I built this one into a U-shaped piece of plastic. This geometry also allows both good stability and airflow, as well as some protection from debris, bumps, and spills.

## Inputs and Outputs

The audio input enters the rear of the amplifier through RCA jacks. Also on the rear of the amplifier are the spring-terminal speaker connectors. The headphone output is on a cabled, 3.5 mm female audio connector extending out the front of the unit (see **Photo 2**).

## Overall Design

These circuit building blocks and simple construction combine to form a safe, reliable, and nice-sounding vacuum tube preamplifier. I built this preamp to last and this design has withstood the test of time. Now, maybe it's time for someone else to build one.

*Editor's Note: All audioXpress articles from 2001 to present can be found on the aX Cache, a USB drive available from [www.cc-webshop.com](http://www.cc-webshop.com).*

Figure 1: This is the final schematic for the desktop vacuum tube headphone amplifier.

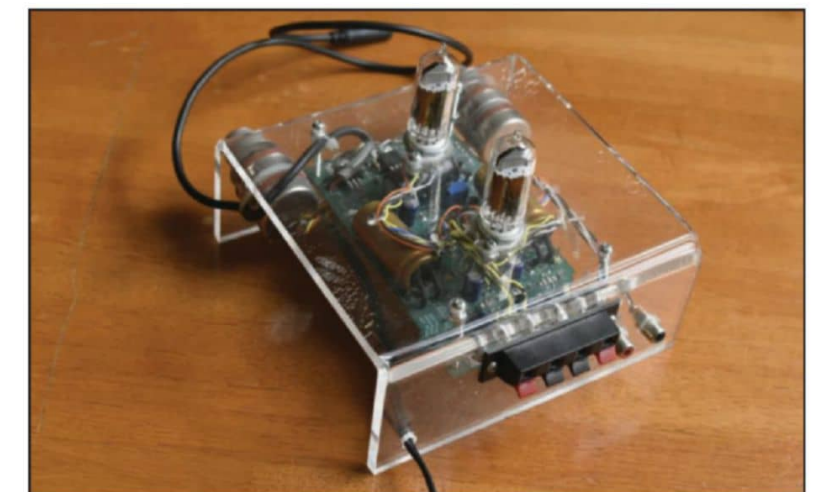


Photo 2: The rear of the amplifier shows the spring-terminal speaker outputs and RCA jack audio inputs.

By  
**Bill Reeve**  
(United States)

## About the Author

Bill Reeve is a retired aerospace engineer and program director. He currently works as a Technical Program Manager at Google.

## Resources

B. Reeve, "Constant Current for Tube Heaters" *audioXpress*, May 2014. Available online at: [www.audioXpress.com/article/constant-current-for-heater-tubes-extend-the-life-of-your-amplifier-s-vacuum-tubes](http://www.audioXpress.com/article/constant-current-for-heater-tubes-extend-the-life-of-your-amplifier-s-vacuum-tubes)

—, "An Alternative to Linear Regulators: Equivalent Power-Line Ripple Rejection with Less Power Dissipation," *audioXpress*, April 2014. Available online at: [www.audioXpress.com/article/an-alternative-to-linear-regulators-equivalent-power-line-ripple-rejection-with-less-power-dissipation](http://www.audioXpress.com/article/an-alternative-to-linear-regulators-equivalent-power-line-ripple-rejection-with-less-power-dissipation)

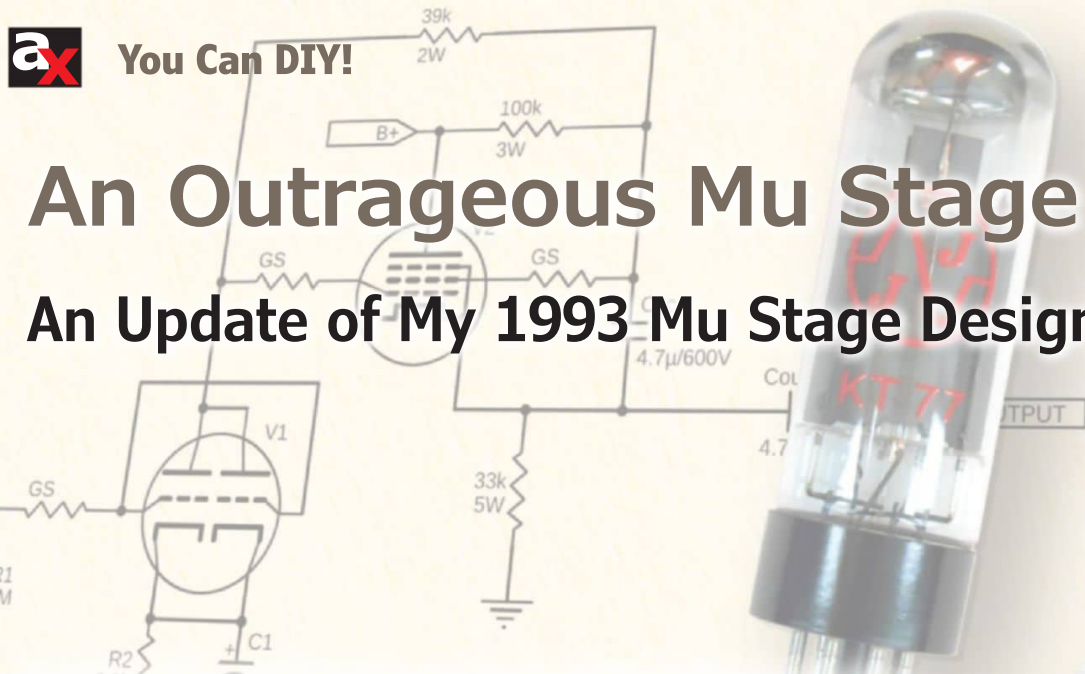




You Can DIY!

# An Outrageous Mu Stage

## An Update of My 1993 Mu Stage Design



Alan Kimmel has built and tested many circuits over the years and he believes the Mu Stage is capable of producing the most constant-current operation as well as very low output impedance. Although the Mu Stage can take many different forms, they basically all work the same way. After revisiting a design concept more than 20 years after he first shared it with audiophiles, he is back to divulge some of the most recent updates of his Mu Stage.

By  
**Alan Kimmel**  
(United States)

In 1993, my first article entitled "The Mu Stage" appeared in *Glass Audio* magazine, the precursor to *audioXpress*. The mu stage concept is to supply a voltage gain triode with constant current so that the triode can attain the lowest distortion. The mu stage also has wide bandwidth. And it has low output impedance to better interface the triode to the real world. Besides low distortion, another effect of constant current operation is that the triode reaches full amplification factor (aka mu).

Since that first article, a plethora of audio circuit design ideas occurred to me—tube, solid-state, and hybrid—all of which were tested and work well. And since that first article a lot has happened with the Mu Stage. Audiophiles worldwide experimented with their own versions of it. Some were very good implementations of the mu stage; others were handicapped with erroneous component values and/or other hindrances, and when the performance or sound of their poorly designed mu stage disappointed the builder, he was inclined to dismiss the mu stage. I commend everyone who built their own mu stage! Some succeeded well, while other attempts were

crippled—this is normal with most audio circuitry with which beginners experiment. But overall, it appears that most implementations of the mu stage around the world are a credit to the mu stage concept.

Though most people praised the mu stage, as with any innovation there were two or three naysayers. They criticized the screen grid bypass capacitor and dropping resistor, conjecturing that this RC introduces low-frequency problems. If the dissenters had actually tried a proper mu stage, they would have found no problem. Too small a screen bypass capacitor or dropping resistor will attenuate bass response, but with adequate screen RC values low frequencies are not attenuated; large RC values are not required. Large enough screen RC values eliminate any concern about low frequencies; a huge capacitor is not necessary for excellent low-frequency response. But just for the fun of it, I tried a small floating DC screen supply to eliminate the screen dropping resistor completely.

This worked well, but proved to be one of those "diminishing return" things—using a small DC floating screen supply wasn't really worth the marginal

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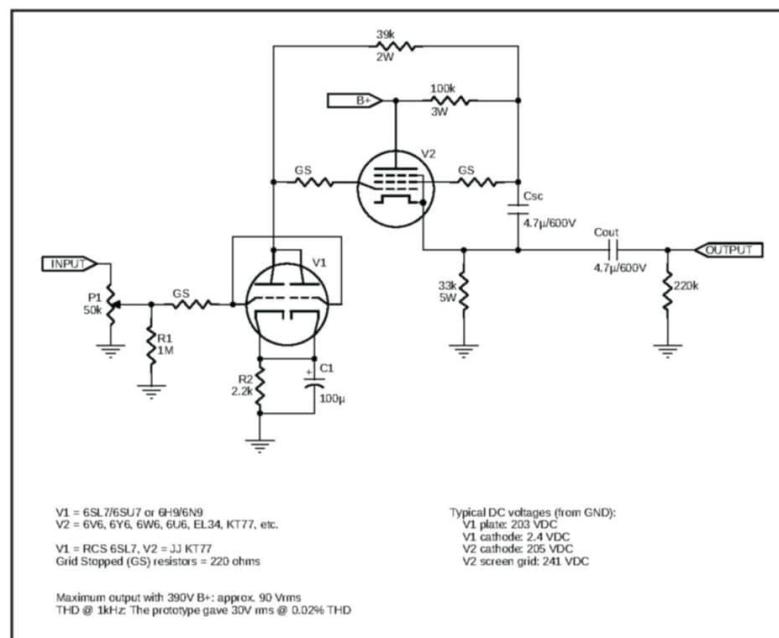


Figure 1: The schematic of my simpler and improved all-tube mu stage

improvement. Just use adequate screen RC values, and make sure that the capacitor voltage rating is higher than the total B+ voltage of your mu stage power supply.

## Screen Grid Surprise

One unexpected surprise showed up with the screen dropping resistor: In some mu stages, this resistor reduces distortion because it turns out that some pentode cathode followers actually like the



Photo 1: This is the JJ Electronic KT77, which is a beam power pentode with an octal base. According to JJ Electric, it can be used in most EL34 amplifiers.

extra load of the screen dropping resistor! But if for purely psychological reasons someone still objects to the screen bypass capacitor and dropping resistor, that person can replace the screen dropping resistor with a small floating screen DC supply and get a marginal improvement. Or, they can build a Hybrid Mu Stage.

## Hybrid Mu Stage

The Hybrid Mu Stage was also discussed in my 1993 *Glass Audio* article. My hybrid mu stage has a MOSFET on top and a triode on bottom. Though even a hybrid mu stage often sounds better than a plain textbook triode stage (which has only a plate resistor on top of the triode), an all-tube mu stage tends to sound even better than a hybrid mu stage.

## Improved Mu Stage

Since that 1993 article, one of my goals has been to improve and, if possible, simplify the all-tube mu stage. That led to the more simple and improved all-tube mu stage shown in **Figure 1**. At first I used smaller power pentodes in this circuit, which worked well. But one day I decided to try something just a tad outrageous, so I tried a JJ Electronic KT77 for the power tube (see **Photo 1**). Lo and behold, the distortion reached a new low! The prototype with 6SL7 triode on bottom and JJ KT77 power tube on top gave me lower distortion than I had ever seen.

No other stage I'm aware of—tube or solid-state—can provide 30 Vrms output at 0.02% total harmonic distortion (THD) at 1 kHz, with no negative feedback. This stage revealed how exceptionally linear that RCA 6SL7 was, as well as what low distortion the JJ KT77 is capable of as a cathode follower in this mu stage. Depending on which tubes you use, your results will vary. The circuit is very versatile. For example, a 5751 triode can be used in place of the 6SL7. Even more versatility is possible regarding the pentode on top.

So many power pentodes and beam tubes have a pinout similar to KT77, that you can make an awesome line stage or driver stage, which will let you roll a nearly endless variety of power pentodes and beam tubes on top. Tube rolling in this stage is optional. (Tube rollers need robust tube sockets that can endure much tube changing.)

In both the old Mu Stage as well as this new streamlined version, the "upper" tube is a cathode follower. One reason this simpler Mu Stage is better than the old one is because this new Mu Stage uses a significantly larger value plate load resistor for the triode (the "bottom" tube), and it does this with no penalty of reduced voltage swing. The larger plate load resistor allows more thorough bootstrapping.

Pentode CF V2 bootstraps a constant screen voltage for itself, and a constant plate current for V1.

To me the appeal of this new streamlined mu stage is that it is both better and simpler than the one I introduced in 1993. This new one should also prove easier to determine the resistor values that give the best operation. The old mu stage can be made to allow both V1 and V2 to have similar power ratings (if that matters to anyone). But generally speaking, in this new streamlined mu stage it is probably best for V2 to be of larger power and current rating than V1—exemplified in my Figure 1 example, which is why I nicknamed it “The Outrageous Mu Stage.”

Notes: The single most important DC voltage is the DCV at the cathode of V2. This DCV should be approximately half the B+ DCV. The easiest way to adjust this DCV is by adjusting the value of the 39 kΩ resistor. The cathode of V2 will be at approximately 200 VDC, therefore, V2's heater supply should be floating. V1's heater supply should be grounded and separate from V2's heater supply. Grid stopper resistors are oscillation insurance and should be mounted as close to the tube as possible. Generally speaking, it is a good idea to use grid stoppers in all audio circuits, not just in the mu stage.

## About the Author

Alan Kimmel is a freelance analog designer. His interests include Electro-medicine, a field that deserves and needs far more attention and research. His website is [www.alansspecialcircuits.com](http://www.alansspecialcircuits.com).

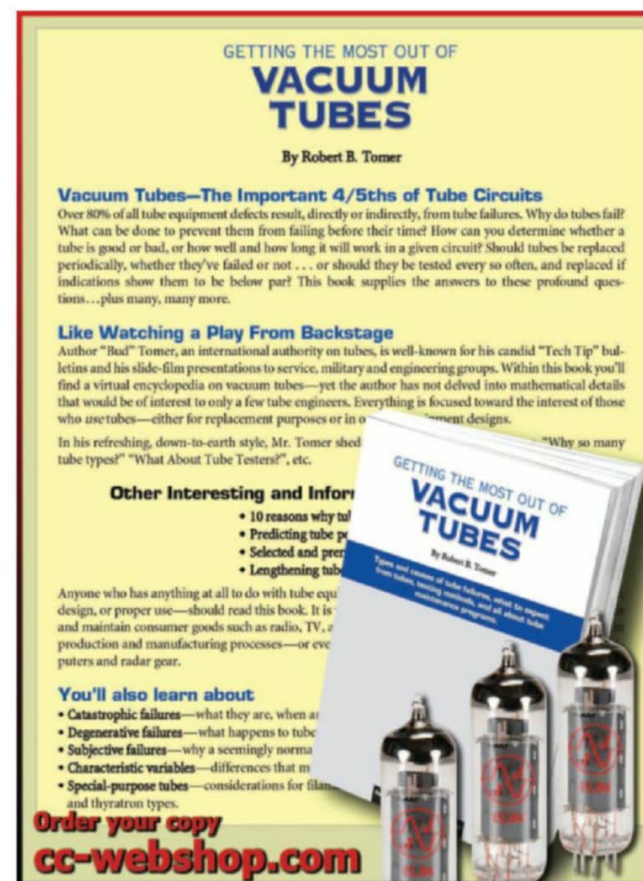
## Conclusion

Using a KT77 for the pentode in this circuit could be perceived by some as slight overkill—but you can't argue with results. You don't have to use a KT77; as mentioned, smaller pentodes work well in this circuit. Best performance occurs when the power pentode or beam tube on top is rated significantly higher power than the triode on bottom. Have fun with it! 

*Author's Note: I prefer to let others say what they think of the sound quality of anything I design. When I design an audio circuit or product it is my habit to not voice the design at all—I just design it and toss it out there to swim or sink. For many years this approach has served me well. It will be great if a reader builds this Mu Stage and reports what he hears. I can be reached at: [airdlab@engineer.com](mailto:airdlab@engineer.com).*

## Resources

A. Kimmel, "The Mu Stage," *Glass Audio*, Volume 5, No. 2, 1993.



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# Experimentation Opened a Realm of Possibilities

## Interview with Shannon Parks, Founder of Parks Audio

By  
**Shannon Becker**  
(United States)

**SHANNON BECKER:** Tell us a little about your background.

**SHANNON PARKS:** My father is an Electrical Engineer, so oscilloscopes, resistors, capacitors, and soldering irons were always around as I grew up. It always seemed that some device—maybe a TV set or computer—was torn apart and being repaired at our house. I remember being excited at one point as he designed a handheld wood moisture meter, and the two of us etched the PCBs and made a piece of electronics from scratch in our basement. This was around 1985. He briefly considered selling them, but the project just wasn't polished enough for a consumer device. This was as close as I came to engineering pursuits in my younger years and I developed other interests. After high school, I went to a small liberal arts college and received a non-technical degree.

Several years later during the height of the dot-com boom, I took a few computer classes at a local community college. They were exciting times, and I began to consider a technical career. With that training, I secured a position as Lab Technician at a family-owned RF engineering company in 2001. Over the next decade there, I got to learn on the job. Working at a small business like that allowed me to pick up all sorts of skills: designing and testing

electrical devices, providing customer support, and basic accounting principles. I think it was like an EE and MBA degree for me.

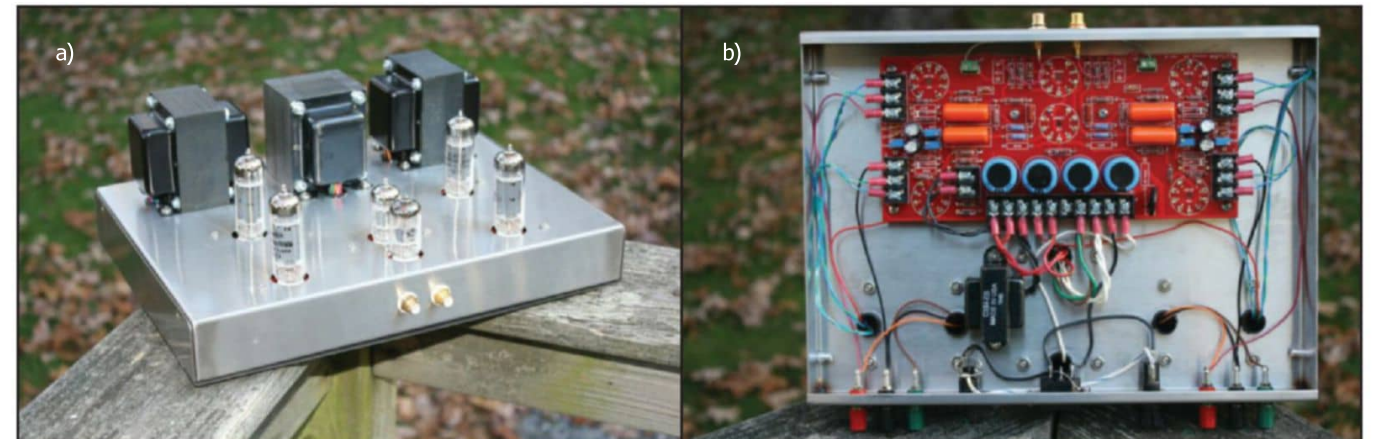
**BECKER:** Can you share some information about your first tube amplifier—a clone of the Dynaco ST35—that you built in 2001?

**PARKS:** When I started my technician job, I still didn't know much about electronics and didn't even know Ohm's Law. It was a stressful transition and I wasn't sure I had the commitment to throw myself into really learning about electronics. Ultimately, I decided to find a complementary hobby. Since I had been a lifelong music lover, I wondered if I could build a tube amp. It seemed like an almost impossible idea, but after diving into the resources online, the circuits seemed simple compared to what I was testing daily at my job. Ned Carlson's tube amp schematic archive and Gary Kaufman's Dynaco archive were extremely helpful at that time. I ended up tearing apart a 50-year-old stereo receiver scavenged from a junk pile at work and rebuilt it as a Dynaco ST35 circuit. It sounded fantastic and I really fell in love with the hobby at that point. This occurred over Christmas 2001.

This first amp was standard point-to-point construction, and I admit it never came naturally



Photo 1: Shannon Parks' DIY experimentation has turned into a thriving business opportunity.



Here is the DIYTube ST35, a clone of the Dynaco ST35 power amplifier shown fully assembled (a) and its inner workings (b).

for me. My wiring was always a mess, and I worried about all the exposed high voltage on terminal strips. So using PCB design tools from work, I started to redo the project with a large PCB based on the ST35. Once finished, I realized that I could order as many boards as I wanted, and maybe others would be interested in the project, too.

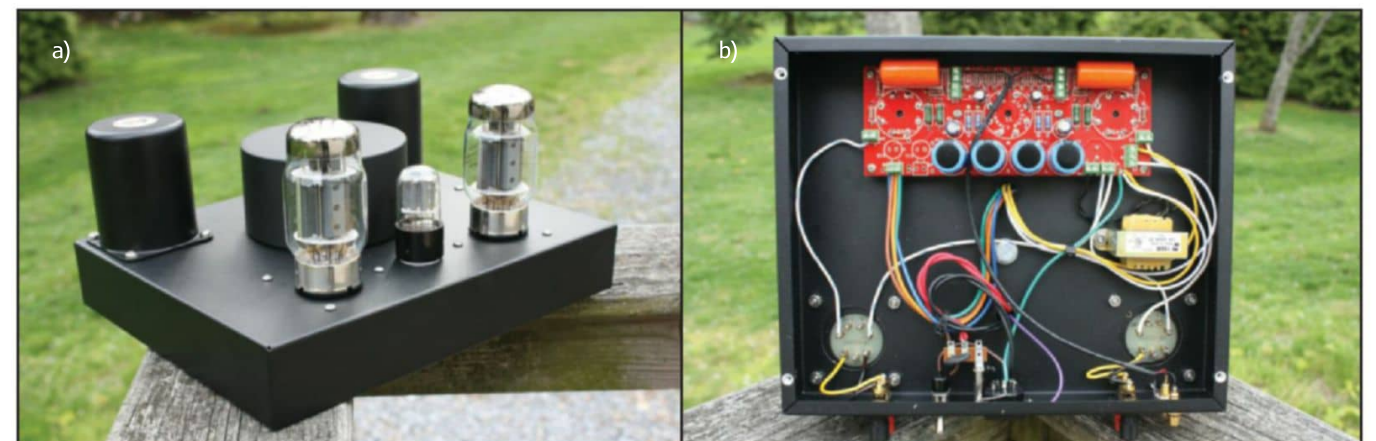
**BECKER:** Tell us about DIYTube.

**PARKS:** I started DIYTube in 2002 to sell the PCBs. I briefly started with a blog format, but quickly switched over to a forum-based website. That allowed me to quickly answer questions and if one person had a question, certainly others had the same question. Often it was me asking the questions. The forum users contributed greatly to that archive, and I, too, learned a lot from the experienced hobbyists. Then over the next few years, I developed more projects in addition to the

ST35 project. I developed Dynaco upgrade boards for the ST70, Mark III, and Mark IV. I created a power monoblock amp project based on the Eico HF60, called the Eiclone. I then created the Get-Set-Go SET amp that used 6B4G triode power tubes. Then probably my most popular design, the Clementine, was a fantastic little single-ended tube amp project that really exemplified the KISS (and acronym for keep it simple, stupid) philosophy. It could be used to build a version of Bob Danielak's classic Darling 1626 amp, or you could build it using beam tetrodes in a triode strapped or ultra-linear configuration.

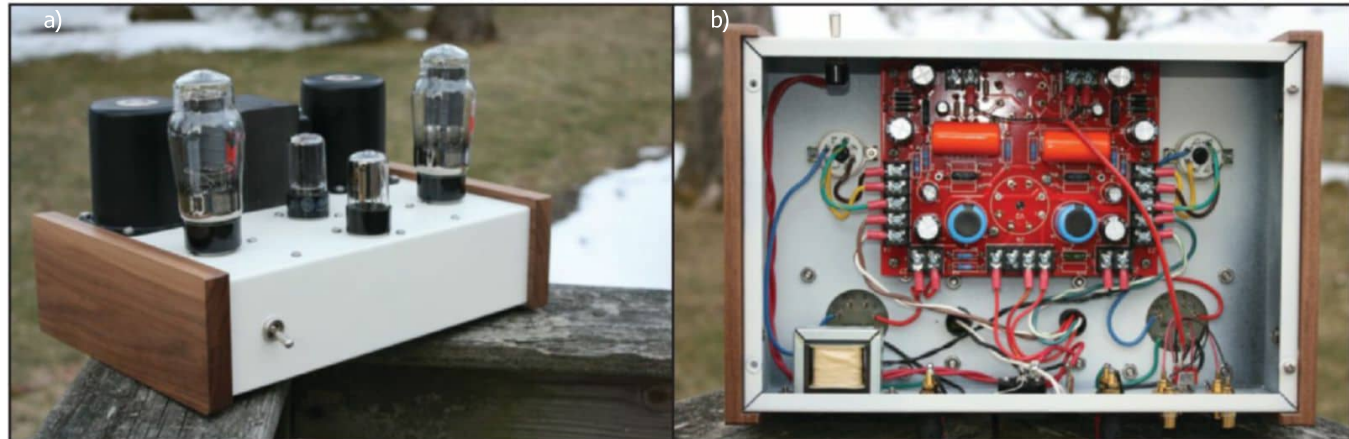
**BECKER:** When did you start Parks Audio ([parksaudiollc.com](http://parksaudiollc.com))?

**PARKS:** In 2010, I wanted to design a new DIY project for a tube phono preamp. I had done a prototype several years earlier, but the noise



This is a Clementine KT88 triode-strapped single-ended amp, shown fully assembled (a) and its inner workings (b).





A Get-Set-Go 6B4G directly heated triode single-ended amp, shown fully assembled (a) and the inner workings (b).

performance was poor and I abandoned it. Dusting off my earlier design, I incorporated some of Walt Jung's low-noise techniques described in his "Sources 101" articles (*audioXpress*, April and May 2007). I selected the 6DJ8 tube for its low noise, and then realized its high perveance also permitted a much lower voltage at the plates. This was a bit of an "Ah ha!" moment. I found a sweet spot in their operation where you could bias them at about one-third typical current, yet still get high transconductance and linearity. This permitted a much lower plate voltage and seemed a safer design with longer tube life.

Over the next two years, my Budgie phono preamp evolved from a DIY project to a commercial product that I was producing in my garage and selling on eBay. I had sold only eight Budgies when I decided to quit my job during the summer of 2013 and work full-time manufacturing phono preamps, transitioning DIYTube into Parks Audio, LLC.

**BECKER:** Back in July 2014, *audioXpress* ran an article that you wrote entitled "Budgie: An Arduino-Based Tube Stereo Preamplifier." Can you share a little information about the Budgie?

**PARKS:** That design was an attempt to grow the Budgie family of products. It was a line stage preamp with remote control for switching sources. The tube was the 12B4, a true triode with very high perveance that could work with only around 20 V on the plates. I used an Arduino Nano plugged into a 32-pin DIP socket as the microcontroller portion.

**BECKER:** How was that Budgie received?

**PARKS:** Unfortunately, the Budgie Arduino project

was a flop. My guess is that if you draw a Venn diagram of tube DIYers and microcontroller hobbyists, you probably end up with a pretty small number of people, so it didn't get much interest from the public. Just a few months later, I decided to stop selling my PCB designs altogether and focus on consumer audio products, which was the Budgie phono preamp and a couple different step up transformer designs for moving coils.

**BECKER:** When did you relocate to the Pacific Northwest? And why?

**PARKS:** The early 2014 North American cold wave was a pretty miserable time for us living in the prairie of Illinois. Meanwhile, the Parks Audio business seemed to be growing enough to support our family and we needed to expand the workspace, then confined to a bathroom-sized room attached to my garage. So we started researching areas with pleasant climates combined with a good mix of civilization and nature. We ended up in Poulsbo, WA, which is smack dab in the center of the Puget Sound area. It's a semi-rural area on the edge of the Olympic National Park, but also just an hour away from Seattle via a fun ferry ride. I can take an afternoon off and go crabbing or visit Pike Place Market.

**BECKER:** Where did your love for high-quality audio come from? And how has it evolved?

**PARKS:** I loved going through my parents' record collection as a kid in the 1970s, playing it on their Allied tube-based hi-fi system. That took up a lot of hours in my young life. Entertainment options were limited, with just three TV stations (no ABC reception), no video games, no DVDs or movies, and no Internet. I also remember playing a lot

with an old crank-based Victrola that came with a couple stacks of 78s. Then my older sister started buying 45s to play on her Emerson table top stereo system and she also listened to *American Top 40* with Casey Kasem. The music seemed so exciting and was a real thrill for me.

Several years later when I got my first modest stereo, I started to purchase Beatles and Led Zeppelin CDs—one album a week purchased with money from my after-school job. Soon I switched to records, as I could buy three used records for the price of one CD, and the record shops had a better selection, too. As a teen I'd burn incense, turn out the lights, and put on the headphones. Great memories. About this time my uncle took me under his wing. He was a self-professed audio guy, with a wall of records, a McIntosh amplifier, and four JBL L100s set up in the corners of his listening room. We've visited many record stores together over the years, and he was instrumental in getting me interested in tube amplifiers, too.

**BECKER:** What is your current focus?

**PARKS:** I stopped selling my PCB designs, which allowed me to completely focus on supporting vinyl playback for vinyl enthusiasts. It's great to have a narrow focus of what I should be doing and what I'm good at. It keeps me from working in areas that others are much better at and permits me to continue getting better at my craft.

**BECKER:** Can you tell us about the Puffin?

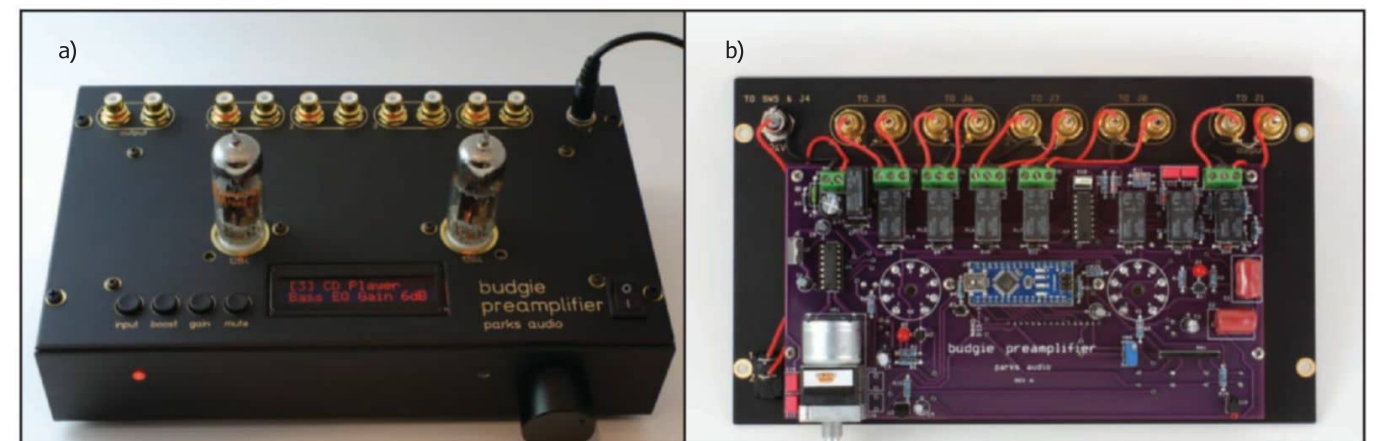
**PARKS:** The Budgie Arduino may have been a flop, but I thought I might be able to salvage some of it, though I had no idea how. In early 2017, I received *The Audio Voice* newsletter from *audioXpress* editor

João Martins with an announcement for license-free DSP software to be used with low-cost ARM microcontrollers. I was intrigued by the possibilities, and after research determined I could write my own code in C using the DSP libraries provided by ARM for the Cortex-M processors. Some DSP concepts are pretty easy to understand. For example, you can easily scale a stream of audio samples by a single number. Multiply it by 0.5, and the signal drops by 50% or -6 dB. Multiply the samples by -1 and you invert the signal.

The possibilities almost made me shake with excitement. I could couple my low noise analog gain techniques with a DSP "brain" that would do all the RIAA equalization, so that I wasn't stuck with a single feedback network that required high tolerance parts. It could also widely adjust the gain range without feedback network error. It could even support all the alternate equalization methods used in the 20<sup>th</sup> century—not just for LPs but also 78s.

I had a very early DSP prototype working about a month later using some evaluation boards from eBay. With this proof of concept I was convinced it would be a huge step forward and a ground-breaking device. I then continued Puffin R&D for a year, launching it this past May. At the same time, I discontinued my Budgie phono preamp and completely changed over—and bet everything on the Puffin.

The Puffin has a lot of surface mount components so I now use a US-based PCB assembler. I then solder all the through-hole components and do the rest of the assembly myself. In this way the quality control is entirely me, and I think that is extremely important. Those days working as a lab tech have paid off, as I run each Puffin through a custom automated test system that takes a ream of data to make sure they function perfectly. I listen to each one of them and then package them up for shipment to Amazon,



The Budgie was a line stage preamp with remote control for switching sources, shown fully assembled (a) and with the cover off (b).





The Puffin has a completely adjustable preamp that then hands off the incoming signal to the DSP.

though I do some direct sales from my website, too.

**BECKER: What do you personally like about the Puffin?**

**PARKS:** Beyond the retail product itself, the Puffin is a test bed for innovation in my lab. The Puffin has a completely adjustable preamp that then hands off the incoming signal to the DSP. At that point, using just a few lines of code, I can create a completely new audio “circuit.” This permits extremely fast prototyping and experimenting. I can spend an afternoon experimenting with high-frequency phase response that would take a lot of work in the analog realm—so much work that you never bother trying it. These flights of fancy and brainstorming can be tested, which for me, is incredibly exciting.

For example, the Puffin has a Transfer Function (TF) setting that enables the user to add second harmonics, which can add 5% THD to the signal, equivalent to a SET amp. Now, I’ve always heard that the second harmonics are sweet sounding, but I’ll be honest, I can’t tell the difference with it on or off. The ramifications of this simple test lead me to think that not only are second harmonics not sweet sounding, but distortion numbers from low-order harmonics are no big deal either. That’s a heretical statement for both the subjectivists and the objectivists. There are lots of other, similar psychoacoustic tests I want to try. While these tests may be written about in books and white papers or available in sound editing software, the Puffin will allow real-time experiments across a large user base.

**BECKER: I understand that you provide personal feedback/advice to customers about their audio system configurations. Why do you think that is an important aspect of your business?**

**PARKS:** Going back to my DIYTube days, I’ve done my best to correspond with customers and to help them work through problems or to just improve their systems in general. I’ve always done it via email, which has frustrated some people wishing to use the phone, but this lets me work most efficiently and permits me to do some thinking, researching, and calculations, before responding. The Budgie was much more limited than the Puffin as it was purely a fixed gain moving magnet phono preamp, so I always wanted to double-check with the customer that the Budgie would be a good fit for them and their system. I turned away a lot of customers and tried to recommend a better match, if that was applicable. Admittedly, turning away customers is a bit painful and bad business in the long run, so it’s one more reason that I developed the Puffin to be able to work with almost all phono cartridges and stereo systems.

**BECKER: What are some of the challenges that you face in this highly competitive market?**

**PARKS:** I think dealing with the supply chain is the most challenging part of my business. The Puffin has 57 line-items on the bill of materials and running out of inventory with just one item can grind everything to a halt. Then as a small business, I just don’t have much leverage when dealing with quality issues from large suppliers. Some of these issues contributed to the Budgie phase out, as I was scrapping about half my vacuum tubes and half my RCA connectors due to cosmetic issues during the final year of production.

So I focus on keeping things as simple as possible. On one hand this keeps the cost of goods lower so that you can compete with an affordable product, but also it improves your production process and prevents wasted resources with rework and scrap. A great historical example of this is when Chuck Peddle’s team took Motorola’s 6800 microprocessor and distilled its core functions down to a simpler device, the 6502. This permitted a much higher chip yield per wafer and a miraculous \$25 microprocessor. Steve Wozniak then used the 6502 in the Apple computers and the rest is history. Even all our smartphones, with their ARM cores, can be traced back to the simple 6502.

**BECKER: Tell us what makes Parks Audio different.**

**PARKS:** My goal is to make products that are



Photo 7: The Budgie phono preamp was Park Audio’s main offering from 2012 to early 2018, in part because it generated a large fanbase due to its sound.

affordable and manufactured in the US. I feel I’m priced where almost everyone can get a Puffin, and the well-to-do can buy two! Hopefully, my personal service makes that value a tough combination to beat.

**BECKER: What do you feel is Parks Audio’s most successful product to date and why do you think it is successful?**

**PARKS:** The Budgie phono preamp has certainly been my most successful product so far, as it was my main offering from 2012 to early 2018. It was just a great sounding phono preamp that generated a large fan base. I think the adjustable loading was a big part of its success, as you could tweak the resonance of moving magnet cartridges to shift their character toward more warmth or more detail. It also permitted easy tube swapping and customers loved “tube rolling.” Being able to swap tubes around for a different sound was incredibly satisfying.

**BECKER: What’s next for Parks Audio?**

**PARKS:** Having launched the Puffin, my goal is to change the hardware design as little as possible in the coming years. I’m focused on getting Puffins out in the market and in peoples’ systems, and to also improve my production efficiency to meet future demand as the Puffin becomes a more mature product. Meanwhile, I plan to do all my R&D in the DSP realm and add new features to the Puffin firmware over time (with free downloads). I’m hoping I will either make some new discoveries or maybe just employ techniques that may have been impractical with analog circuits. I think the resurgence in vinyl will continue for another 10 years at least, so I will remain focused on vinyl playback. Listening to your favorite LP is almost a religious experience, and if I can contribute in a small way to peoples’ happiness and joy in this area, then I am satisfied.

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# Searching for a Unicorn (Part 1)

## Measuring Voltage Regulator Ripple Rejection

Voltage regulators have many specifications such as output current, noise, drop-out, input ripple rejection, and dynamic load transient response. This article examines a search for a true measurement of ripple rejection, also called power supply rejection ratio (PSRR).

By  
**Brian Lowe**  
(Belleson LLC)

About 10 years ago, with my audio system in disrepair, I started a mission to design and build a new preamp. This was a third-generation design, as my first preamp was a tube RIAA unit built in the early 1980s. This one was to be solid state and the first step was to make “the best” power supply. In the December 2008 issue of *audioXpress*, Ed Simon concluded a five-part article on power supplies and cleaning of AC power lines with “The best solution is a well-designed power supply in the audio gear itself.”

Power supplies have been around since 1800 when Alessandro Volta invented the forerunner to an electric battery. How hard can it be to achieve “the best solution”? Having designed power supplies in the past, and having read a lot through the years, I set a goal of an affordable supply with really solid voltage regulation.

Before inexpensive voltage regulator ICs were widely available (late 1960s), audio gear often had hum, fizz, crackle, and other noises. Well-designed amplification systems typically used differential stages and/or push-pull outputs that canceled hum by summing it with its inverted self to add to zero at the output. Some products had a hum adjustment

potentiometer to allow hum to be manually nulled by increasing the volume and turning the pot until hum was minimized. However, even the best audio equipment had some hum at high volume.

As you know, voltage regulators are everywhere in modern audio gear. Open a DAC, a preamp, a mixer, a CD player, MP3 player, cell phone, computer, music server and you’ll find them. Complex mixed analog+digital ICs often have them built in, and the venerable LM78xx, the LM317, and their more modern descendants often grace the pages of this periodical. The primary function of these devices is to take anything you feed them, AC, DC, lightning, or firecrackers, and turn it into clean, quiet, perfectly flat DC voltage that’s constant for every output current load condition, under every temperature, humidity, atmospheric pressure, and political upheaval circumstance.

Voltage regulators have many specifications such as output current, noise, drop-out, input ripple rejection, and dynamic load transient response. This article examines a search for a true measurement of ripple rejection, which is also called power supply rejection ratio (PSRR).

### Ripple Rejection

Ripple rejection is somewhat of a misnomer, named for the ripple that appears on a linear transformer rectifier-filter-type raw power supply. An ideal regulator, if one existed, would reject not only the inherent ripple from this, it would reject a digital spike, a sub-1 Hz slow thermal variation, and so forth. The most common cases are at the low-frequency end as power line ripple (normally a saw-tooth wave at twice the power line frequency of 50 Hz or 60 Hz).

At the high-frequency end, a switched mode power supply (SMPS) can produce spikes from tens of kilohertz to megahertz. Also, more recent switching audio amplifiers have transient noise as non-periodic digital noise source due to pulse width modulation (PWM) inside the amplifier. Recently, a manufacturer of Class D power amps told me high-performance voltage regulators made a “significant performance impact in our product.” High-frequency, uncorrelated supply noise can make its way to places like a clock circuit, increasing jitter and thus causing data errors

in a DAC or ADC.

Thus, high ripple rejection across a wide bandwidth can improve the fidelity and integrity of traditional mains-to-transformer powered audio, SMPS powered audio and Class D PWM type audio. This includes equipment used by both the recording and playback sides of the industry.

IC op-amps often have a specification of more than 100 dB power supply rejection. If you look further at the datasheet to PSRR vs. frequency, rejection rolls off rapidly as frequency increases. It may decrease by 10 or 20 dB at a few kilohertz. Thus, variations in the raw power supply can make their way to the audio path through an op-amp. Discrete, single-ended designs are potentially worse yet, as they don’t have a way to null supply variations like a differential topology does.

### Regulator Designs

So back to the search for “good regulation,” I spent a month or so researching various regulator designs including super regulator designs like those

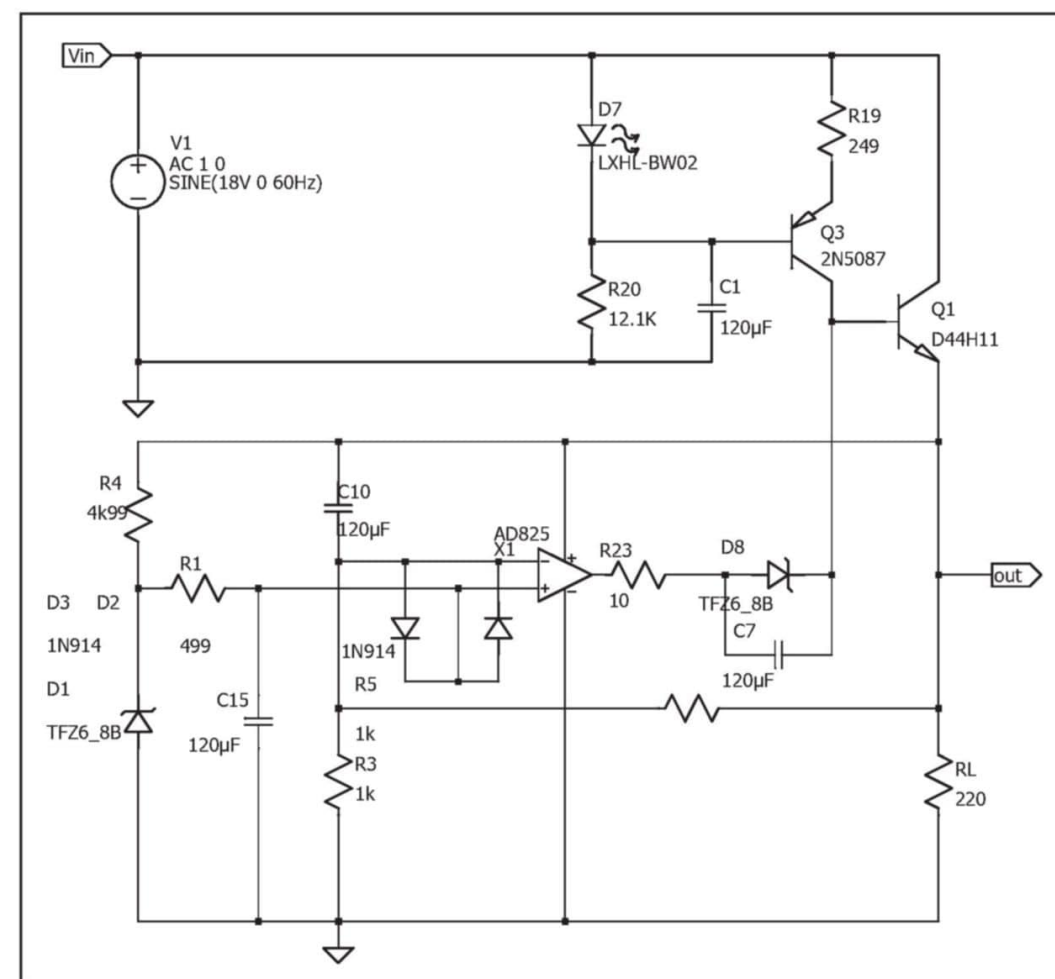


Figure 1: This is the schematic for the Walt Jung design.



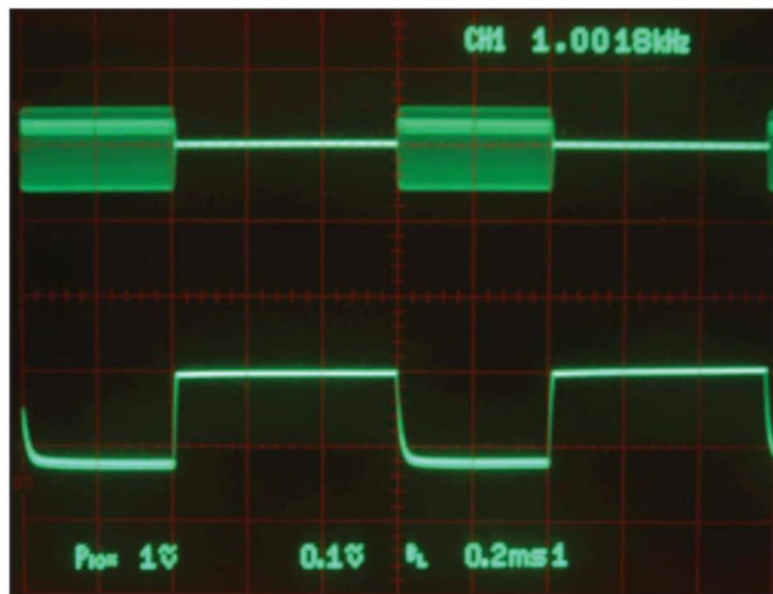


Figure 2: Walt Jung/Jan Didden regulator's instability is shown. The top trace =  $V_{out}$ , the bottom represents the output load current of the regulator.

presented by Walt Jung, one by John Roberts in a preamp in a 1985 issue of *Audio Amateur*, a 2007 variation of the Jung regulator from Zetex (now called Diodes, Inc.), and a great historical analysis of regulator evolution by Tangentsoft. These are known as series regulators because the regulator is in series with the load current, vs. a shunt regulator which regulates by having a fixed load current that is steered either to the load or shunted to ground. While I later looked at shunt regulators, they are not a topic in this article.

Interestingly, the John Roberts regulator circuit was not discussed as being anything extraordinary. Described by Roberts as "my simple op-amp/transistor regulated power supply," it, in fact, has all the facets of a true super regulator (SR), with both the error amplifier and voltage reference bootstrap powered by the regulated output. It also has tracking dual polarity outputs, supplying negative and positive 15 V, and preceded the publication of Jung's bootstrapped regulator by 15 years.

Given that a SR's error amplifier drives the

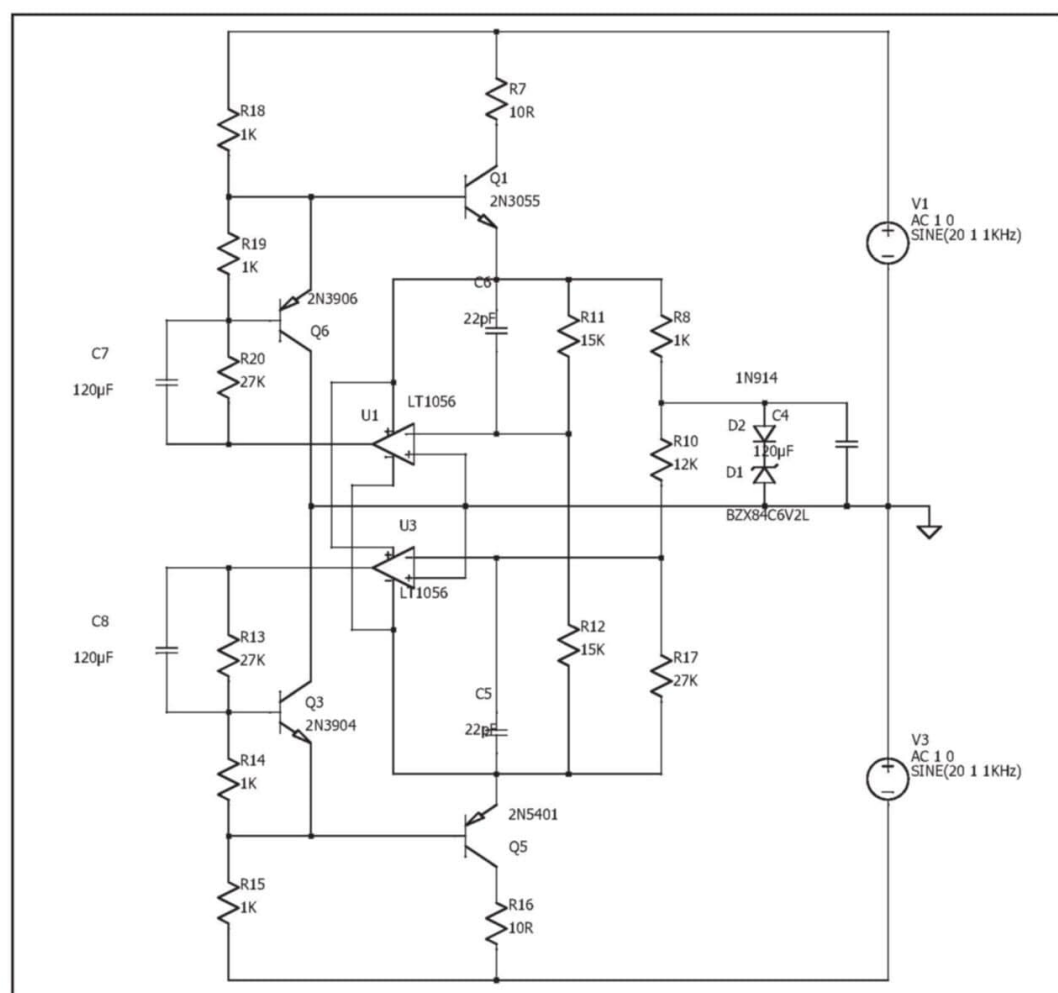


Figure 3: John Roberts' design is a dual-polarity tracking super regulator where the negative half establishes a regulated output and the positive half follows by inverting it.

output device and is simultaneously powered by that same output voltage, there must be a voltage level translation to keep the op-amp's output voltage within its power rails. This is accomplished in the Roberts supply with clever transistor biasing, while the Jung SR uses a Zener diode on the op-amp's output. **Figure 1** shows the schematics for the Jung design.

There are disadvantages to the Jung design, including its physical size due to several large electrolytic capacitors, its start-up issues as detailed in Jung's 2000 *Audio Electronics* article (see Resources), its necessity of a ground connected voltage reference, and its limited output current. In my analysis of the AD797 version, there was also an instability problem within a range of output current for the specific breadboard tested (see **Figure 2**).

Roberts' design (see **Figure 3**) is a dual-tracking regulator where the negative half establishes a regulated output and the positive half follows by inverting it. The Jung/Didden design uses a current source to drive the output transistor, with excess current pulled away by the loop control amplifier. A Zener diode shifts the loop amplifier output higher than its power supply, allowing it to be powered by the regulated  $V_{out}$ .

The Roberts design uses a voltage follower scaled by a resistor divider. The 1 k $\Omega$  resistor from  $V_{in}$  couples ripple to the base of Q7 output transistor so, while I never built this design, I suspect it has relatively high ripple. Note that the original design used a TL072 dual op-amp, where this one shows two LT1056A, which are similar JFET input op-amps.

As the general consensus in DIY postings favored the Jung version, I built one and began experimenting with ways to better implement the level shift. Ultimately, I figured out that a JFET's gate-to-source voltage could be used to do the level shift and, when combined with a shunt voltage reference, allow the entire regulator control loop and reference to float. This gives the possibility of a low component count, low noise, high current, high voltage bootstrapped regulator. In 2010, I filed for a US patent for this design and it was granted in 2012.

Referring to **Figure 4** (taken from the patent) notice how only the drain of J1 and collector of Q1 are connected to the raw input supply. The drain and collector are both high impedance nodes and all the other regulation circuitry is within the control loop. Unlike the other designs, there are no other paths for ripple (or any sort of undesired signal) to reach the regulated output. Thus, this design should be capable of very high ripple rejection.

With this verbose introduction, we now embark on a long and perilous journey to measure ripple rejection.

## Measuring Ripple Rejection

There are several important regulator specifications: line regulation, noise, output impedance, load transient response, and load regulation. The goal is to find out if the circuit of figure has slayed the line regulation dragon. Line regulation is also called power supply rejection ratio (PSRR) and ripple rejection. The latter phrase

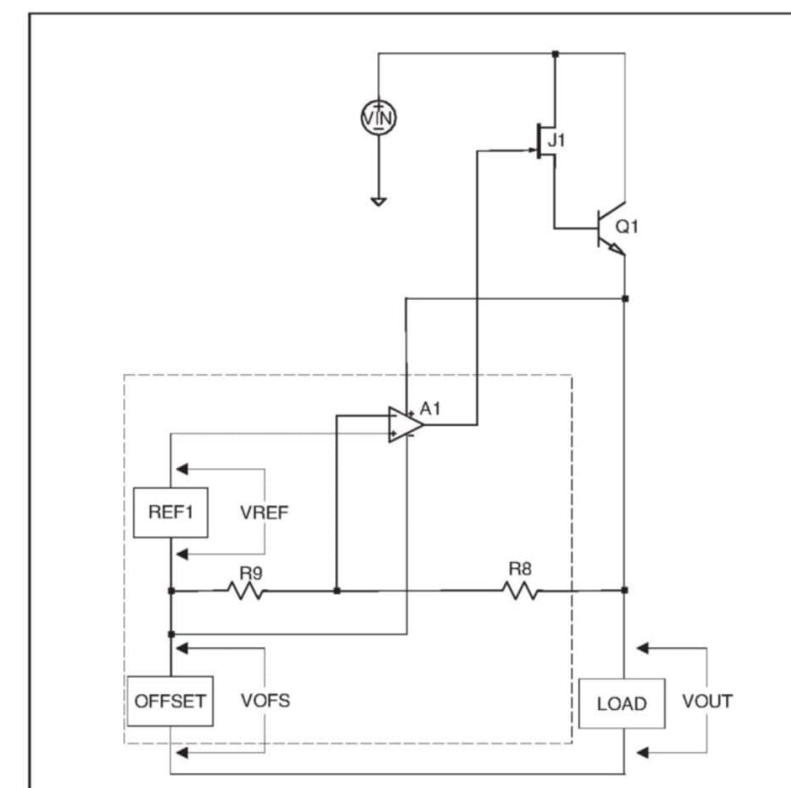


Figure 4: This schematic was taken from the US Patent, which was granted in 2012, for my design.

## About the Author

Brian Lowe is founder and principal engineer at Belleson LLC. His audio circuit design experience dates to 1971, when he designed a reverb unit using a ceramic phono cartridge, four ball point pen springs, a model car hub cap, a transistor amplifier kit, and a speaker. In the 1980s, he was author of an article in Issue 1 of *Glass Audio* called "A Self-Bias Servo for Push Pull Amps," and in 1984 he designed a diamond tester. He received US patent 8294440 in 2012 for a novel voltage regulator. He's a proud father of two thriving teenagers and spouse of a very tolerant and patient wife.



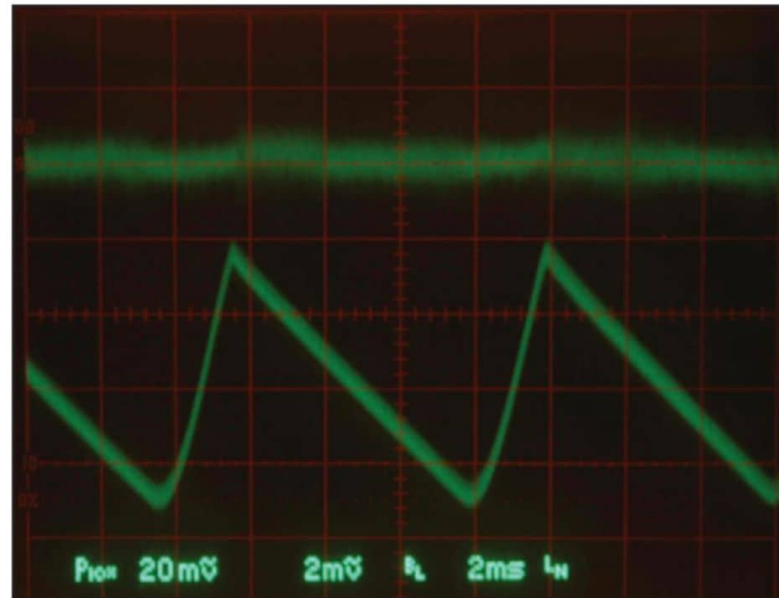


Figure 5: Sawtooth ripple is measured from a rectified and filtered transformer (bottom trace).

seems the most descriptive and will be used here.

A voltage regulator is fundamentally a power transformation device that ideally should replace any sort of incoming power—AC, DC, pulses, noise, whatever, with a pure, constant DC voltage that can supply any current requested by a load. The question we want to resolve is how close can a regulator come to that ideal as it relates to rejecting the non-DC portion of incoming power?

Semiconductor manufacturers use expensive automated test systems to test ripple rejection. In the early 1980s, these systems were really good at testing digital components and not so good at testing

analog parameters. One of the primary objectives was keeping test times low, and component specifications were sometimes tailored to make devices look as good as possible. For example, power supply rejection was tested by making two DC measurements at two different input voltages and taking the ratio of the change in  $V_{out}$  to the change in  $V_{in}$ . This is a very lightweight test that allows a datasheet to look really good on the line for ripple rejection. It gives some indication of ripple rejection at low frequencies, thus of its ability to clean power line ripple coming from a rectified and filtered AC source (see **Figure 5**).

As we know, things get more complicated as frequency goes up. In the mid-1980s, the advent of consumer CD players introduced audio systems containing digital signals in the same chassis and on the same board as analog signals.

Connection traces became more critical and power supply ripple rejection too, at frequencies well beyond 50 Hz or 60 Hz. Voltage regulators became more than a power transformation... when used strategically they also became a way to isolate different functional sections of a circuit system. And ripple rejection across a wider frequency band became much more important.

Automated test systems used by semi manufacturers (e.g., those made by Teradyne) naturally have improved their equipment to do more thorough characterization of various parameters across frequencies. Small companies and DIYers don't have the cash for a multi-million dollar machine, or maybe even for the electrical service to power it. There are other alternatives such as those from Audio Precision that are "more affordable," in the range of a few tens of thousands of US dollars. This is still not an option for many, so what's a bright designer to do?

A typical analytic approach to bench test ripple rejection across a broad frequency band is to impose a sine wave at various frequencies onto a DC voltage. Thus, a power source of DC + sine wave is set as regulator  $V_{in}$ , with conditions that the lowest point of the sine wave is above the drop-out voltage of the regulator, and the highest point is below the maximum DC of the supplying input source and below the maximum regulator  $V_{in}$ . This seems easy enough, right? In the intervening 10 years since I first began measuring ripple rejection I've tried numerous ways to generate a source signal good enough to span zero to 200 kHz and give accurate results for a regulator with exceptionally good performance. Some were okay and some not so much.

In the second part of this two-part article, we'll take a look at them.

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# Square-Wave Testing

Richard Honeycutt explores the value of square-wave testing and shares what these tests actually reveal.

By  
**Richard Honeycutt**  
(United States)



Photo 1: Hewlett Packard 200A audio oscillator

In the early days of electronic audio, engineers and serious home listeners learned to appreciate things they'd never thought about in connection with music listening: frequency response and power levels. The first radios were wonderful if you could hear and understand the announcer. When music began to be regularly broadcast, just hearing it was enough.



Photo 2: Early Hewlett-Packard frequency-response tester

## The Evolution of Music Equipment

By the 1930s, some listeners had developed the skills to judge realism in broadcast from reproduced-from-shellac music. By sometime in the 1940s, home phonograph playing systems had started to include the frequency response in their advertising, sometimes with graphs. Audio amateurs, especially those who built their own electronics from scratch or kits, naturally wanted to be able to measure the frequency response of their creations. This was not an easy proposition at the time.

Early audio signal generators made by companies such as Hewlett Packard (HP) advertised a sine-wave output that was uniform within  $\pm 1.5$  dB from 20 to 20,000 Hz (see **Photo 1**). The experimenter could feed a sine wave to the input of his/her home-brew amplifier and measure the output on an AC voltmeter or oscilloscope. By about 1942, HP had introduced the Model 205AG signal generator that contained both an audio oscillator and an AC voltmeter (see **Photo 2**). This lovely marvel allowed frequency-response testing using just one piece of equipment. Price being an issue for most experimenters, the introduction of audio signal generators by Eico, Heathkit, Precision, Brüel & Kjær (B&K), and other manufacturers in the 1950s was warmly welcomed; but these tended to have much greater variation in output amplitude with frequency than the HP's signal generator. Thus, getting accurate results required

monitoring the input level to the device under test (DUT) while measuring.

The Eico 377 (see **Photo 3**)—and many subsequent moderately priced audio signal generators—had a new feature: a square-wave output. At roughly the same time, some speaker manufacturers (notably Jensen) had introduced bass-reflex speakers (see **Photo 4**), and some home-builders imitated these speakers with greater or lesser success. (We now call this type of speaker system a “vented” speaker, and due to the research of A. N. Thiele in the 1970s, we have the theoretical understanding that enables us to build excellent speakers using this principle. But I digress...) Critical listeners eventually came to suspect the whole genre of bass-reflex speakers because of the boominess of many of these early examples. (I must mention at this point that the Jensen Imperials were, in fact, well-designed, and one of these served as the lobby monitor speaker in a radio station at which I worked in the late 1960s.)

## Audio Shortcomings

Discussions in hi-fi magazines pointed to a shortcoming beyond the excessive bass response: poor transient response resulting in smeared sound. Someone realized that using a square-wave input to the amplifier driving a speaker would enable the designer to view the response on an oscilloscope and evaluate the accuracy of the transient response. The square wave was viewed simplistically as an alternation of infinite frequency (the rise and fall portions) and zero frequency or DC (the flat top and bottom). To the extent that the speaker could produce a good square wave, it could be expected to exhibit good transient response. In testing using square waves, many experimenters realized that the output waveform from the DUT also revealed information about the frequency response. It was often claimed that a sloped (rather than vertical) rise or fall indicated

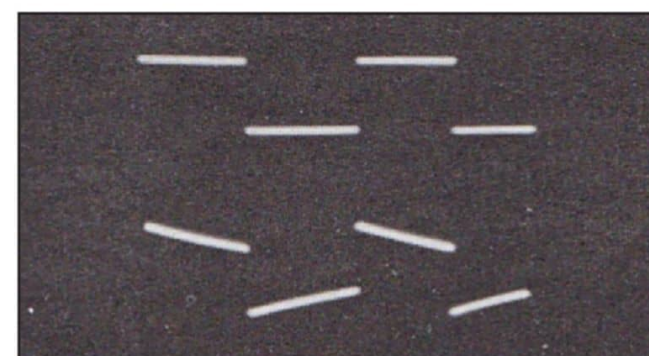


Figure 1 : Here is a 40-Hz square-wave test.

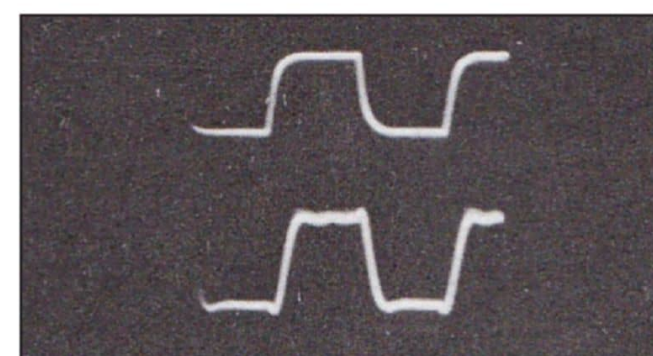


Figure 2: The 10-kHz square-wave test shows some ringing in the DUT.



Photo 3: Eico Model 377 audio signal generator



Figure 4: The Jensen Imperial bass-reflex speaker system



Figure 3: Sum of the first five terms of the Fourier series composing a square wave

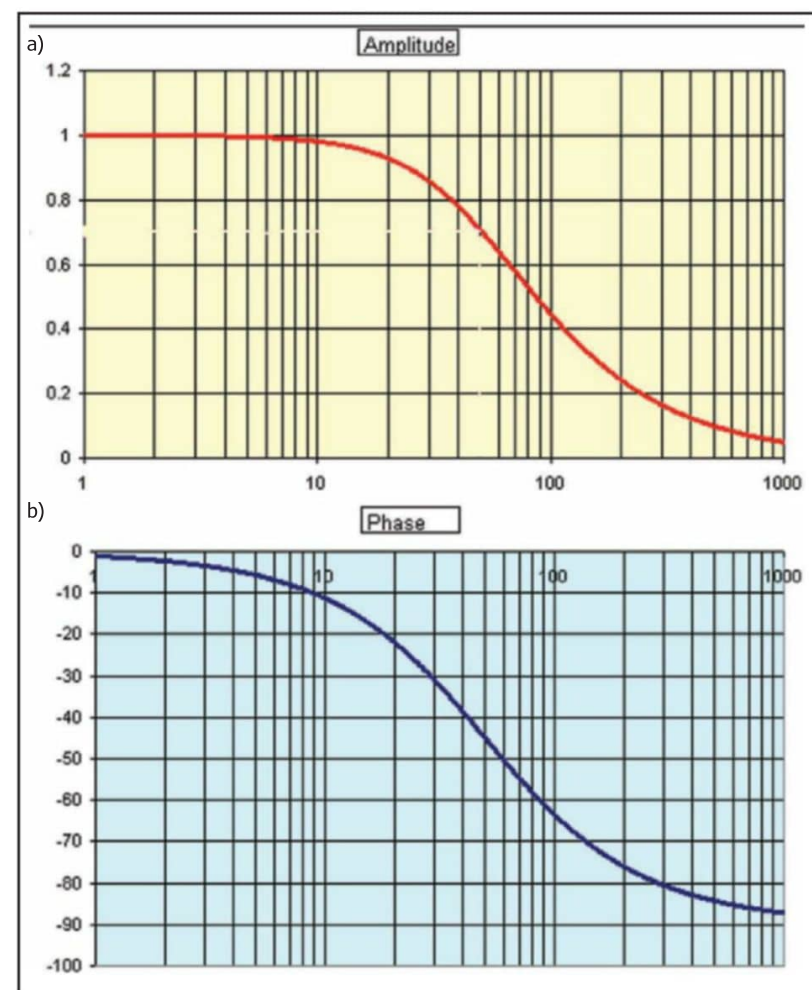
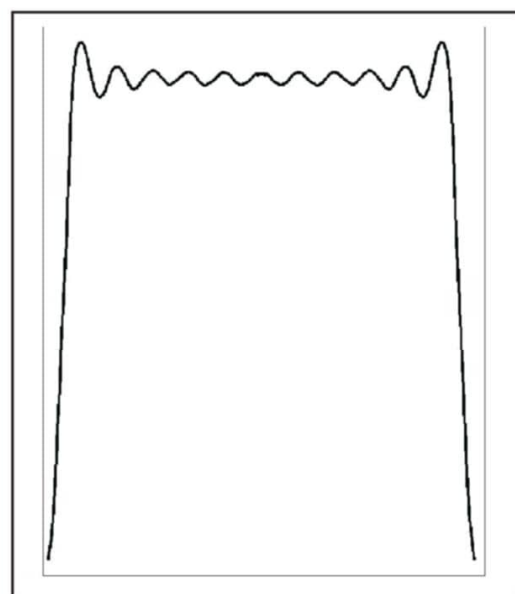


Figure 4: Relation of phase to frequency response—(a) gain vs. frequency and (b) phase shift in degrees vs. frequency.

poor high-frequency (HF) response, and a sloping top or bottom indicated poor low-frequency (LF) response. This simplistic approach was exciting, because in the days before computerized frequency-response analyzers, it seemed to allow anyone with a square-wave generator and an oscilloscope to quickly approximate the frequency response of a DUT, without laboriously writing down a list of frequencies and levels for later graphing.

**Figure 1** shows a 40-Hz square wave test of a power amplifier, with the traces photographed by an oscilloscope camera (hence, no grid lines). The upper wave is the input wave. The lower wave has very fast rise and fall, indicating good HF response. The sloping top and bottom actually indicate LF phase shift, even though the amplifier's LF response extended well below 40 Hz.

In the 10-kHz square-wave test shown in **Figure 2**, the upper trace (input) shows imperfect HF performance in the signal generator, and the lower trace (output) shows some ringing in the DUT, possibly from imperfect choice of frequency compensation components in the feedback loop.

### Helpful Background Information

Before continuing our story, we need to discuss a little background information that has become more widely known since the early days of audio. Fourier's theorem states that any waveform can be deconstructed into a sine wave (the "fundamental") at the same frequency as the wave under discussion, added linearly to integer multiples ("harmonics") of that fundamental frequency. The amplitude of a given harmonic nearly always is inversely related to the harmonic number. Thus, the second harmonic's amplitude is normally less than that of the fundamental; the third harmonic's amplitude is even less, and so on. A triangle wave is made up of a fundamental and all odd harmonics, with each harmonic's amplitude inversely proportional to the square of the harmonic number. So if you have a 1,000-Hz triangle wave with a 1 V fundamental, it will also have a 1/9 V component at 3 kHz, 1/25 V at 5 kHz, etc.

More to the point of our present discussion, a square wave consists of a fundamental and all odd harmonics, with each harmonic's amplitude inversely proportional to the harmonic number. So a 1-kHz square wave will have a 1/3 V 3-kHz component, 1/5 V 5-kHz component, etc.

**Figure 3** illustrates the waveform produced by adding the fundamental and lowest four harmonics of the Fourier series composing a square wave. From this illustration, you can see that omitting the

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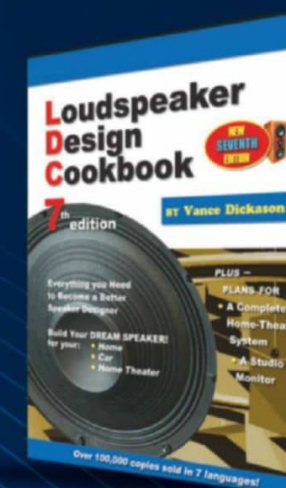






Figure 5: A test square wave produced by an Eico 390 signal generator

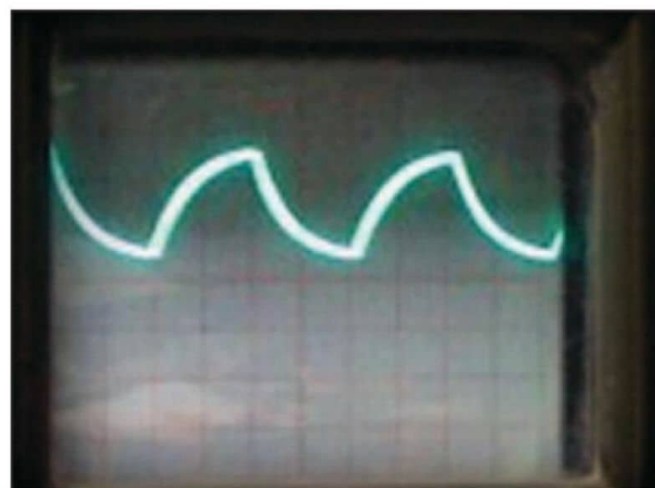


Figure 6: Here, a square wave has passed through a 475-Hz low-pass filter.

harmonics having frequencies above 14 kHz not only makes the rise and fall non-vertical, but it adds ripples to the top and bottom. So the simplistic understanding of square-wave analysis was incomplete.

Digging further into Fourier analysis of a square wave, we find that the phase of the harmonics affects the composite waveform. Although there was little interest in the phase response of audio equipment before at least the advent of stereo, phase effects unavoidably come into play in the action of circuits that limit HF or LF response. This fact is illustrated by the output amplitude and frequency response plots of a 500-Hz low-pass filter shown in **Figure 4**.

Michael Lawrence has developed an Internet utility that enables users to adjust the amplitude and phase of frequency components in a square wave and

instantaneously see how the wave shape is affected (see Resources). In playing with this utility, you will find that adjusting the phase of the amplitude tilts the top and bottom of the square wave. Excess or deficient LF components with no phase shift (not a normal condition in practice) cause a hump or a scoop-out in the top and bottom portions.

The 1969 edition of Howard Tremaine's *Audio Cyclopedia* has a full-page illustration to help interpret square-wave responses. In general terms, sloped but straight-line tops and bottoms are caused by phase shift between lower- and higher-frequency components. Scooped out tops and bottoms indicate poor LF response. Squiggly tops and bottoms indicate ringing, usually caused by poor damping or faulty frequency compensation.

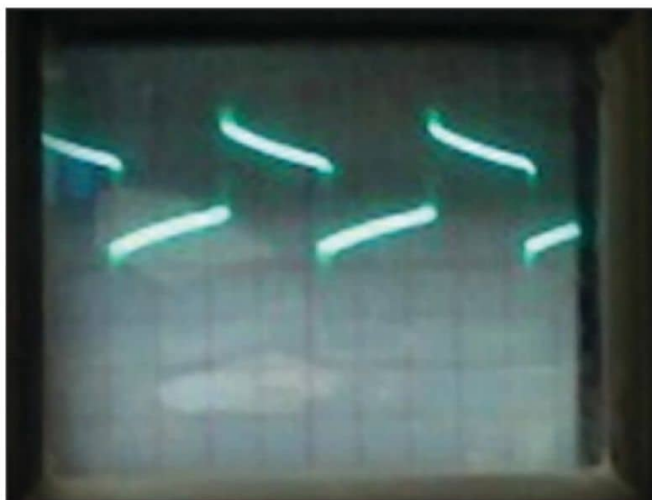


Figure 7: Here a square wave has passed through a 475-Hz high-pass filter.



Figure 8: Here are the effects of more extreme high-pass filter with a cutoff frequency of 1.6 kHz

## Resources

M. Lawrence, Square Wave Terms, [www.desmos.com/calculator/lgl6i8may](http://www.desmos.com/calculator/lgl6i8may).

H. Tremaine, *Audio Cyclopedia*, Howard W. Sams & Co.; 2nd edition, 1969.

## Examples of Frequency Response

Now let's look at some actual examples of the effects of frequency response and the accompanying phase shift on a 400-Hz square wave. **Figure 5** shows the test square wave produced by an Eico 390 signal generator. You'll notice some rounding on the leading shoulder, indicating that the generator itself does not have perfect HF response. **Figure 6** shows what a 475-Hz low-pass filter does to the waveform. **Figure 7** shows the effects of a 475-Hz high-pass filter. **Figure 8** shows the effects of a more extreme high-pass filter with a cut-off frequency of 1.6 kHz.

## The Test Frequency in Square-Wave Testing Matters

The choice of test frequency for square-wave testing is important. A DUT will always have a LF limit that acts as a high-pass filter, and a HF limit that acts as a low-pass filter. Since there is no component having a lower frequency than the fundamental, the test frequency will not show the effects of high-pass filtering below its fundamental, except for sloping tops and bottoms due to phase effects. High-frequency effects will show up for low-pass filter

cutoffs up to at least 10 times the test frequency. So the 400-Hz test wave we used in Figures 5-8 would reveal frequency response issues between about 400 and 4,000 Hz. In the days when audio equipment manufacturers sometimes published square-wave responses in their specifications, they often used two test frequencies, such as 40 Hz and 10 kHz. Strictly, this would leave the 400-to-10,000-Hz range untested, but users have generally been more interested in the response extremes than in the midrange.

One final comment: Both low- and high-frequency square-wave tests almost always reveal issues for speakers and transformer-coupled amplifiers. Really good square-wave test results on these are rare. I had considered including the square-wave test output for a McIntosh power amplifier, but it looked so much like the test wave that it was almost indistinguishable from Figure 5. My only comment would have been how very unusual it is to see such perfect test results from a hollow-state power amplifier! 

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# Corrections to the “Noise in Vacuum Tube Circuits” Article

By  
**Richard Honeycutt**  
(United States)

We would like to thank our astute reader, Burkhard Vogel, for bringing to my attention some errors in “Noise in Vacuum Tube Circuits,” published in the February 2019 issue of *audioXpress*. In the article, I included my equation (4), below, derived from G. L. Pearson’s 1934 Bell System Technical Journal (BSTJ) paper<sup>[1]</sup>:

$$\frac{v_n}{\sqrt{\text{Hz}}} = \sqrt{4kT_0 \left( \frac{r_p}{\mu} \right)^2 \left[ \frac{T_1}{T_0 r_p} + \frac{1}{r_0} \right]} \quad (\text{H4})$$

Vogel pointed out that this equation does not give the correct results. Instead, he gives an equation that leads to:

$$\frac{v_n}{\sqrt{\text{Hz}}} = \sqrt{4kT_0 r_N} \quad (\text{V6})$$

where I have substituted  $T_0$  for his  $T_1$ , meaning the temperature of the external components in the circuit, and  $r_N$  (the “noise resistance”) is defined as follows:

$$r_N = \frac{3.06}{g_m} \cong \frac{2T_1}{3T_0} \frac{1}{\sigma g_m} \quad (\text{V7})$$

Since  $g_m = \mu/r_p$ , equation (V6) becomes:

$$\frac{v_n}{\sqrt{\text{Hz}}} = \sqrt{4kT_0 \frac{2}{3} \frac{T_1}{T_0} \frac{r_p}{\sigma \mu}} = \sqrt{4k \frac{2}{3} \frac{T_1 r_p}{\sigma \mu}} \quad (\text{VH1})$$

where I have substituted  $T_1$  for his  $T_c$ , meaning the triode’s cathode temperature.

In Pearson’s paper, his purpose was to develop an equation that predicts the noise that can be measured at the plate of a triode amplifier stage. This measured value would necessarily include the noise contributed by the external plate load (plate resistor in parallel with the connected AC load resistance). Vogel and I concentrate only on

the noise generated in the tube. Consequently, I should have omitted the second term in the brackets under the radical in equation (H4). Further, I should have noticed what appears to be a typo in Pearson’s equation (4), from which I derived (H4): the quantity under the radical should be inversely proportional to  $\mu$ , but in Pearson’s equation (4) and in (H4), it is inversely proportional to  $\mu$  squared. Since Pearson backed up his calculations with measurements, I believe the error crept in when:

$$\frac{r_p^2}{\mu}$$

in his handwritten manuscript was entered as:

$$\left( \frac{r_p}{\mu} \right)^2$$

Otherwise, his measurements would have revealed the error. Incorporating these corrections, (H4) becomes:

$$\frac{v_n}{\sqrt{\text{Hz}}} = \sqrt{4kT_1 \frac{r_p}{\mu}} \quad (\text{HC1})$$

Both (VH1) and (HC1) mathematically describe the Johnson noise generated in a triode as being approximately equal to that generated by a resistor having the value of  $r_p$ , at the temperature of the cathode. As you can see, equations (VH1) and (HC1) differ only by the factor  $(2/3\sigma)$ . Since Vogel gives the value of 0.8 for  $\sigma$  (the “accuracy control factor for triodes”), this factor is numerically equal to about 0.833. Vogel’s work is based upon Telefunken publications<sup>[2]</sup>. I presume that Telefunken took their noise analysis further than Pearson had done by the time he published his BSTJ paper in 1934, culminating in their including this correction factor, which amounts to less than a decibel in predicted noise level.

I apologize to our readers for the errors in my February 2019 Hollow-State Electronics article.

Vogel also made comments concerning the effect of the 47 k $\Omega$  input resistor (control-grid-to-ground) in a common moving-magnet phono preamplifier, and the effect of flicker noise. These issues will be addressed in a future Hollow-State Electronics article. 

## Resources

[1] G. L. Pearson, “Fluctuation Noise in Vacuum Tubes,” *Physics*, September, 1934.

[2] Telefunken AG, 1965 “Telefunken Laborbuch 1 ... 5” (Telefunken Lab Handbooks), Franzis Verlag, München.



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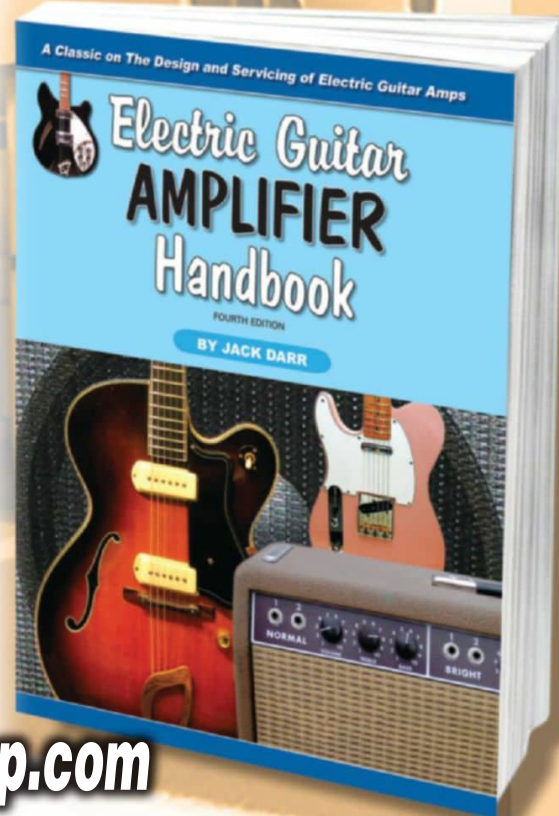
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