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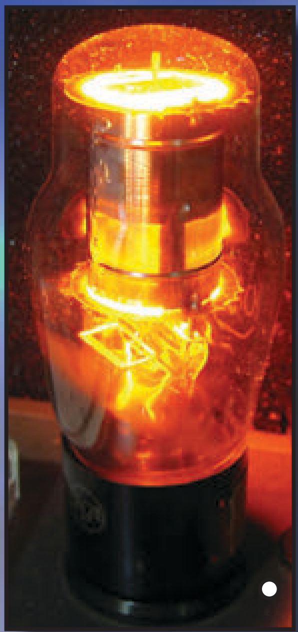

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- DC Power Offers Edge Over AC for Indirectly Heated Tubes
- Air Motion Transformer Technology Revival in Speaker Products
- Test Results: A Compact Driver from Italy and Ribbon Tweeters from Taiwan and China
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From the Editor's Desk

Art and Craft

This month *audioXpress* showcases art and craft in audio design. You'll find both as you read about handcrafted power cables, updated bookshelf speakers, high-performance ultra-compact drivers, and more.

A few good things came out of the disco era—including a custom-made speaker cable that addressed sound-quality issues arising from cables running near discotheque strobe lights. Ray Kimber devised that hand-braided cable, inspiring Kimber Kable company and its handcrafted audio and video cables (p. 27).

Ron Tipton explains how he updated a pair of MTX Audio Monitor 5i 5.25" bookshelf speakers to use with a new computer (p. 15).

You can best test a newly designed loudspeaker by comparing its sound to what you hear through high-quality headphones. Top-notch amplifiers drive such headphones. George Ntanavaras describes how he built a high-power headphone amplifier (p. 20).

Nine years ago RCF, a global player in pro audio loudspeakers, renewed its commitment to product research, development, and manufacturing in Italy. It has launched many new products since. Vance Dickason tested one—the ultra-compact ND950 1.4 neodymium compression driver and its complementary HF950 injection molded composite horn (p. 34).

If you're a hobbyist who is considering swapping out rectifier tubes in your audio equipment, you should take a few precautions. Find out what they are in Richard Honeycutt's article comparing solid- and hollow-state rectifier tubes (p. 30).

Which is better for heating tube amplifiers? Alternating or direct current? It's an ongoing debate. Gerhard Haas examines the data and concludes that despite the prevalence of AC, DC offers clear advantages for indirectly heating vacuum tubes (p. 12).

Regards,
Mary Wilson
editor@audioxpress.com

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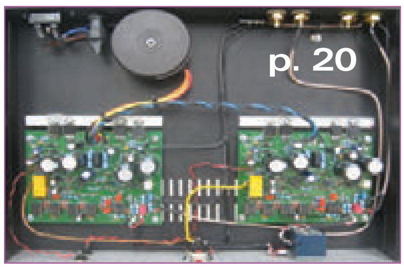

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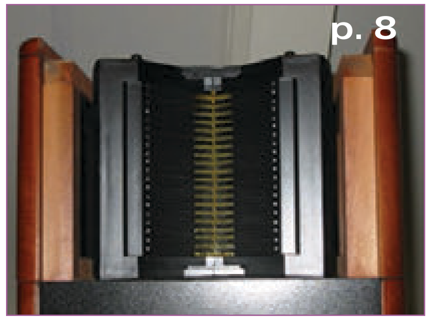

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By Mike Klasco and Steve Tatarunis (United States)

The Air Motion Transformer

Companies worldwide now use innovative technology in loudspeaker products

The Air Motion Transformer (AMT) is a loudspeaker invented by Dr. Oskar Heil (1908–1994). With patents in early radar and microwave work dating back to 1972, Heil was a noted German-born physics researcher. He also made significant contributions to the concepts that eventually yielded the field-effect transistor (FET).

ESS Laboratories bought the rights to the AMT when the first patent was granted in 1972. The company's first product was the AMT-1 (see **Photo 1**). For the next two decades, ESS held the Heil and AMT tweeter patents. From 2002 through 2009, the five patents progressively expired. However, ESS speakers could be obtained from the Sacramento, CA-based company until 2006. And in Germany, it was possible to get ESS speakers (new or classic designs) as well as the ESS AMT drivers from the local ESS affiliate until it ceased to operate in 2009. Today, there is a resurrected ESS in El Monte, CA (in the Los Angeles area), that once again offers the product line.

AMT'S UNIQUE DESIGN

An ingenious and innovative operating concept, the AMT shares design elements similar to those found in planar magnetic ribbons but with a folded rather than tensioned diaphragm. With the AMT, the pleated diaphragm compresses and expands in a physical motion similar to that of an accordion. The AMT's diaphragm, like the planar ribbon, typically has an aluminum conductor pattern of flex circuit construction.

The low-mass diaphragm is folded and suspended within a dipole magnetic field. When a signal current passes through the aluminum strips, the ensuing bellows-like motion of the folded pleats moves air faster than it would with a conventional cone driver. This rapid acceleration of air motion is said to provide enhanced sound reproduction. The result is a dipole driver with a fast response, enabled by the film diaphragm's low mass and the smaller displacement on each cycle compared to non-pleated drivers.

Photo 1: Unlike a normal piston loudspeaker, the ESS Air Motion Transformer linearly squeezes and expands its diaphragm.

Each diaphragm flexure's discernible motion is small, but because of the folded structure it moves more air than a conventional cone or planar driver would with the same baffle area. A standard 1″-wide (25-mm) AMT strip has a more functional driver area than an 8″-diameter (200-mm) circular dynamic cone. The folded driver design, combined with the small motion range, means the AMT acts like a point source version of a larger driver.

ESS's literature has described the AMT movement by saying it "spits" the air out in a way similar to the action of shooting a watermelon seed from your hand by squeezing it between the thumb and the forefinger. The speed of the air as it leaves the diaphragm is approximately five times faster than the speed of the actual driver structure, hence the name, Air Motion Transformer. Another advantage is that the conductors (i.e., the driving "stripes") are in direct contact with the outer air and can more easily dump the heat—so thermal power compression is minimized. This is important because ESS's original AMT diaphragm was made of a Mylar ribbon. This substrate does not have a high temperature tolerance.

The AMT can reproduce sound down into the lower midrange, providing reasonable design trade-offs in driver size, sensitivity, and lower midrange extension. The folds in the diaphragm have the less obvious benefit of providing structural integrity to the moving system even though it is very low mass. Thus, potential operation into the upper bass region is possible if the driver is scaled up in size.

An AMT diaphragm can be operated without the magnetic field, using piezoelectric polyvinylidene difluoride (PVDF) high-polymer film technology. TakeT has used this method for its headphone and tweeter products, which we explored in last month's column.

HISTORY AND REBIRTH

The AMT's first implementation, the AMT-1, resembled a truncated, four-sided pyramid. Its system combined the AMT driver with a 10″ woofer and a bass port. The product had a large impact on the stereo market, arriving at a time when the AR-3A was fading and the Bose 901 direct/reflecting speakers and JBL's L100 (the ones with the brightly colored foam grills) were dominating the mainstream (at $500 a pair).

ESS has faded from the speaker industry, yet today, the AMT driver has far greater market acceptance than it did when it was first introduced 40 years ago. The reasons for this are diverse, ranging from expiring patents to neodymium magnet technology's ability to provide the performance that ferrite and samarium cobalt magnets could not deliver in the days of the original AMT design. Another factor

is the advances in diaphragm materials. The material used in the ESS AMT diaphragm's construction—polyethylene terephthalate (PET), which is also known by its trade name Mylar—has decent acoustic characteristics but a much lower thermal tolerance. It was too easy to deform or fry the diaphragm on the ESS drivers. Mylar is no longer used in the construction of planar ribbon and AMT drivers. It has been replaced by substrates with superior characteristics—polyethylene naphthalate (PEN) films (e.g., Teonex), polyetheretherketone (PEEK) film (e.g., APTIV), and polyimides. In today's consumer electronics, the AMT driver is used as a midrange tweeter or as a tweeter in high-end multi-driver speakers. Sometimes it is even paired with horns.

Photo 2: The TakeT Batpro tweeter is a super-tweeter that reproduces a high tone to improve sound quality. (Photo courtesy of TakeT Corp.)

Photo 3: The ADAM Audio F5 Active Studio Monitor is the smaller of the near-field monitors and has been designed for listening environments with somewhat limited space. (Photo courtesy of ADAM Audio)

Photo 4: The Precide ERGO AMT headphone employs an Air Motion Transformer driver. (Photo courtesy of Precide)

Several companies now produce or market AMT transducers. TakeT (Japan) has its Batpro tweeter (see **Photo 2**). Other companies include: Advanced Dynamic Audio Monitors (ADAM) Audio (Germany) with its eXtended Accelerating Ribbon Technology (X-ART), ELAC (Germany) with its JET tweeter, Emotiva Pro (US) with its Airmotiv, ETON (Germany), FAL (Japan), MartinLogan (US) with its Folded Motion Tweeter, Precide (Switzerland) with its Air Velocity Transformer (AVT), and QMS (China). Tetra (Canada) has a Tetra 606 that uses the Mundorf (Germany) AMT.

Physicist Klaus Heinz can probably be credited for AMT's continued advancements. In his younger days, he was Heil's protégé. In 1999, Heinz along with electrical engineer Roland Stenz founded ADAM Audio. The company has continued to develop, manufacture, and distribute AMT loudspeakers in the professional audio field. Some of the European AMT examples are Klaus's work, and some of the Asian implementations are from ADAM's former vendors, who had the benefit of working with Klaus.

After 10 years, ADAM re-engineered the ART, its version of the original AMT driver construction, and renamed its product X-ART. These new X-ART tweeters and midrange speakers are characterized by an extended frequency range and higher efficiency compared to their predecessors (see **Photo 3**).

AMT IN PRO SOUND

The AMT boasts a number of attributes that hold promise for high-output commercial sound installations and touring sound. The large radiating area becomes compact when folded. The conductor in the magnetic field is spread over a large area. It is also possible to scale up the AMT to radiate a large gradient soundfield. Air distortion is not an issue, unlike a horn where sound intensity in the throat can lead to some nasty output characteristics. Yet the folded diaphragm is stiff enough to drive a horn, and some light horn loading was used in one of the later ESS models. Cerwin Vega developed a more focused effort in horn loading with its AMT variant, and the company was granted several patents. In the 1990s, Cerwin Vega demonstrated a few of its horn-loaded AMT class speakers at pro-sound trade shows and they produced an excellent high-output sound.

The results of combining new substrates for the diaphragm, new bonding techniques, and neodymium magnets should provide an interesting range of pro-sound applications.

AMT IN HEADPHONES

ESS Laboratories's first Heil AMT headphones were essentially ESS AMT tweeters driven at full range. When a tweeter faces into a plane wave tube (or the ear canal), the response below its fundamental resonance is essentially flat and predictable—at least until it runs out of excursion. The ESS headphones were not that impressive.

More recently, Precide manufactured an electrodynamic AMT headphone. Interestingly, its version is a piezoelectric PVDF film AMT headphone. Pioneer first developed the PVDF headphones. Its models used a slightly domed sheet of film that limited the maximum volume of air that could be moved. Currently, TakeT produces a PVDF film headphone and, like the Precide headphone driver, it has a variation in the size of transducer folds over the diaphragm (see **Photo 4**).

Next month, we will look at the microspeaker, which was once mainly used for toys, intercoms, and modest tasks. Today's microspeaker reincarnation is used for headphone drivers, docking stations, compact Bluetooth speakers, HD voice speakerphones, and other high-performance applications. *aX*

MEMBER PROFILE

Member Name: Pierre Touzelet

Location: Vélizy-Villacoublay, a neighborhood in Paris, France

Education: Aerothermal Mechanical Engineering

Occupation: Pierre worked as a technical director in an engineering company that designs and sets up large vibration systems and acoustic rooms for environmental tests. He retired in 2008.

Member Status: He first subscribed to *Glass Audio in 1998* and then subscribed to *audioXpress*. He is a contributor to *audioXpress*.

Audio Interests: Pierre likes to concentrate on audio problems that he feels are not satisfactorily explained from a scientific viewpoint.

Current Audio Projects: Pierre is pursuing two areas of research. The first one studies the use of negative feedback on amplifiers and its influence on their sound. The second project focuses on audio transformer behavior and its audio specifications.

Dream System: Pierre said the solutions currently proposed by the audio industry fall short of his concept for a dream system. Until improvements are made, he said he is content to listen "with great pleasure" to his 42-year-old system, which comprises an ESART IS200 tuner-amplifer (with 40 W per channel), a vintage Thorens TD160 LP player equipped with an ADC XLM MKII cartridge, and two KEF 104 Reference Series loudspeakers.

Pierre said the system is perfect for classical music lovers. He added that he never listens to CDs because of their "cold sound and their questionable recording techniques." Pierre only listens to 33-1/3 vinyl LPs recorded, using an artificial head equipped with two microphones, because he finds it is still the closest to hi-fi stereo reproduction.

Pierre Touzelet

By Gerhard Haas (Germany)

Tube Heating with DC Power

DC-powered heaters diminish mains hum interference

A recurring question is whether or not direct current (DC) should be used to heat electron tubes. Consequently, the literature on the topic provides contradicting opinions. This article attempts to shed some light on this controversial issue based on a few practical thoughts and information from old databooks published by widely renowned electron tube manufacturers.

ELECTRON TUBES

The filament inside an electron tube is a length of resistor wire heated to a defined temperature to make a tube's cathode layer emit electrons. Thomas Edison (1847–1931) discovered how to control electrons flowing through a vacuum while developing his version of the incandescent light bulb. To enable a flow of electrons out of a metallic surface, the temperature has to be correct. Most tubes have a coating similar to some of the properties of semiconductors, which makes the cathode emit electrons at 200°C to 300°C. In contrast, tungsten wire needs a temperature well above 2,000°C. However, it is not critical which specific method brings the cathode to temperature. It is more important to reach and maintain the correct temperature to generate a steady flow of electrons.

DC VS. AC

It is safe to say that it simply does not matter whether a length of wire is heated to temperature by a 6.3 VDC or by a 6.3 V_{EFF} alternating current (AC) since the product of current and voltage is identical. In general, the same statement applies to incandescent light bulbs. They can be powered by either a 230-VDC or a 230-VAC source. The average brightness is the same. However, a DC source will yield a more even flow of light than an AC source. It is customary in highly sensitive optical instrumentation to use DC-powered bulbs because thermic inertia effects prevent a steady and uniform flow of light. The superposition of light flow with a 50-Hz mains frequency would cause measurement errors due to modulation effects.

Most tube databooks only discuss heating with AC power although occasional hints at heating with DC power have been mentioned. However, 40 years ago semiconductors were hard to come by and fairly expensive. Few people attempted to heat electron tubes with well-regulated, DC power. Heating with AC power was simply less expensive. Special tubes were developed to achieve highly sensitive and noise-free preamplifiers (e.g., the ECC 808, which is similar to the ECC 83 with a few important design changes. The most significant design feature was a rearrangement of the pin layout).

The control grids were placed as far from the heater wires as possible and additional shields were constructed inside the tube cylinder (e.g., the EF 86 and the EF 804, which are high transconductance sharp cutoff pentode vacuum tubes). These measures greatly reduced the hum caused by the proximity to the heater. Moreover, the heater wires were twisted. It is now common practice to have twisted-pair wires.

Hum interference can either be induced due to the proximity of the heater wires to adjacent electrodes or straight from the cathode itself, which is mounted close to the filament. If the cathode is connected to a signal ground, hum is not a problem. However, a simple resistor wired from cathode to ground without a capacitor connected in parallel will cause a noticeable increase in unwanted noise. The heater-cathode combination's thermic inertia is likely to cause a modulation of cathode emission with the mains frequency. This is a typical problem with directly heated tubes. For this reason, it has been customary to heat the first tube in the signal chain with DC, particularly in the design of measuring equipment, condenser microphones, and highly sensitive preamplifiers. Only this technique can eliminate hum at the most sensitive spot in the circuit.

Simple heaters are merely V-shaped bent wires. Better quality is achieved using single or double spiral-wound filaments. The spiral winding technique provides a marked reduction of hum entering the tube system via the heater onto the cathode's surface. Most commonly used electron tubes are indirectly heated for good reasons. The twisted heater wire is located inside a cathode sleeve, which elegantly circumvents a number of problems. First, the signal and the heater circuitry are totally separated. Second, the cathode's surface structure and overall design does not interact with the heater wire's shape and properties. The problem with direct heating tubes is that the cathode's shape must match the heater's design since they are essentially the same. Tubes with indirect heating can be powered with DC or AC. However, the correct temperature range must be provided for the cathode to facilitate a flawless emission of electrons. It is possible to operate two heater wires rated at 6.3 V each in series using a 12.6-V source, which creates less power loss and is more efficient. This approach does not present valid concerns if applied to tube types (e.g., the ECC 81, the ECC 82, and the ECC 83). These tubes have been designed to accept either 6.3 or 12.6-V heater supplies. It is also acceptable to wire the heaters of two power tubes (e.g., the EL 34) in series. In fact, it was common practice to wire all heater elements in series in old tube-powered TV chassis. It was considered a reliable technique with a long service life spanning several years.

HEATER WIRING

An important parameter for successful heater wiring is the breakdown voltage between the heater wire and the cathode, which is usually specified as an absolute maximum rating in official datasheets published by the manufacturers. Heater wires in indirectly heated tubes are covered with a temperature-resistant insulating layer. The thickness of this layer correlates positively with breakdown voltage (i.e., a relatively thick layer will need more power to dissipate heat but will provide a fairly high breakdown voltage). In contrast, a thin layer design promotes a better heat exchange at the expense of lower breakdown voltage. In essence, the layer design and thickness of the insulation depend on the desired application and general constraints of tube construction.

CAVEATS WHEN SELECTING AC OR DC

Once AC power has been chosen to heat the tube, it is a good idea to wire the heaters using twisted pairs, referencing them symmetrically to signal ground with two resistors. That yields a symmetrical ground-free wiring that uses signal ground as a reference. Perhaps the heater coil in the power transformer has a center tap that can be grounded, providing the same effect. If DC power is used, it is advisable to also connect the minus terminal to the heater to signal ground for optimum potential equalization. Failure to do this results in an increased hum level because the heater wires are subject to inductive and capacitive interspersions. Since the heater current is relatively high compared to the signal currents, a common ground path for signals and heating is not recommended. The simultaneous superposition will certainly increase the amplifier's noise floor, specifically current noise due to the finite resistance of the wires. A DC-powered heating circuit has yet another advantage because it doesn't produce interfering signals as do AC-powered wires. In general, the choice of well-regulated DC power for heating usually eliminates many problems from the beginning. For example, the wire layout is not critical compared to the AC alternative and makes an existing tube design more robust and insensitive to small changes in internal tube topology. The use of AC

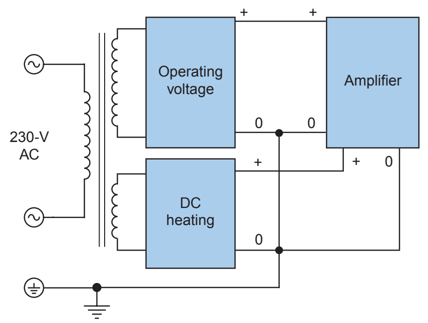

Figure 1: An optimized wiring schematic for DC heating enables you to compensate for fluctuations in mains voltage.

power for heating has caused problems when tubes had to be replaced. One tube increased the hum level, while another tube did not cause noticeable changes in noise performance. The culprit was found after a brief inspection—one of the tubes definitely received interference from the heater. **Figure 1** shows an optimized wiring schematic for DC-current heating.

From a technical and physical perspective, there appears to be no reason to discard DC-powered heating, especially since longitudinal data confirms the service life of the tubes will not be influenced. Tube manufacturers usually specify a ±7% heating voltage range. If in doubt, a slight overheating of the cathodes is preferable over insufficient temperature. A low heater temperature will almost always cause excessive and premature wear. Regulated DC-powered heating circuits can be tightly controlled without much effort and you can compensate for fluctuations in mains voltage. Another plus might be the implementation of a soft-start option. This function will help prolong tube life.

Filaments and incandescent light bulbs usually burn out during start up. The low cold resistance causes a higher inrush current by a factor of approximately 6 A. High initial current will burn out the weakest spot along the filament or heater wire. In general, indirectly heated tubes will benefit from DC-powered heating.

DIRECTLY HEATED TUBES

The situation with directly heated tubes is somewhat different since heaters and cathodes are basically the same component. Sometimes mains hum interference happens inside the tube and cannot be effectively suppressed. Another problem with typically thin heater wires is that their low thermic inertia may cause 50-Hz modulations of cathode emissions. An AC-powered heating circuit simply means that the control grid and the heater-cathode combination are basically on the same voltage potential.

These circumstances can be explained using the 300 B tube variety as an example. The manufacturer recommends –61 V as the correct setting for the grid voltage and the heater requires 5 V. An AC-powered heating circuit does not change this voltage ratio at all, but a DC-current system will produce a voltage mismatch. The positive heater terminal will show a smaller potential with reference to the grid than the negative heater terminal. The imbalance of left and right emissions from the heater-cathode combination traveling to the anode is about 8.2%.

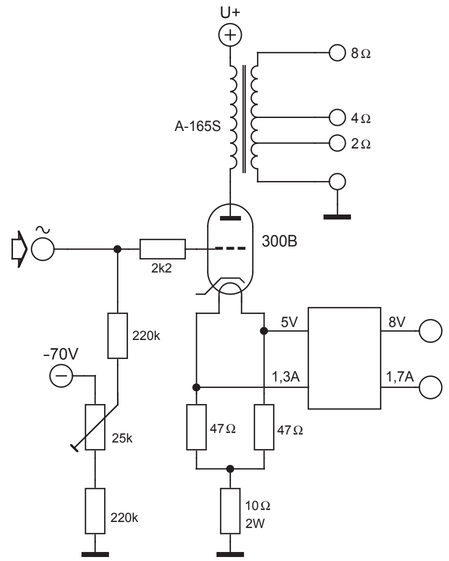

Figure 2: A balance coupling via symmetrical resistors provides a ground reference.

Let us assume that a design calls for a tube specified at 4-V heater voltage and –2-V grid voltage. This arrangement does not work if one side of the heater filament and one side of the cathode are both referenced to ground. Here, the circuit shown in **Figure 2** comes to the rescue.

A balanced coupling via symmetrical resistors for the DC-powered heater circuit provides an elegant ground reference. Indirectly heated tubes make the wiring of the heater connections very easy but directly heated tubes require a thorough inspection of the heater-cathode configuration. Furthermore, directly heated tubes cannot be heated in series. A typical "worst-case" configuration for a tube amplifier would be a separate direct-current heating circuit per tube, which is expensive and significantly increases the power supply's complexity. However, the reward for this increased expense is a low level of mains-induced hum.

DISPELLING DC CONCERNS

To dispel possible concerns about the advantages of the DC heating of tube amplifiers, a historical anecdote might convince any remaining skeptics. The first reproducible current made available to mankind was direct current produced by the so-called Volta column or Voltaic pile. Italian physicist Alessandro Volta (1745–1827)—the source for the term "volt" for the unit of electric potential and electromotive force—developed an electrochemical voltage source that paved the way for today's batteries. His "galvanic cell," based on silver and zinc disks submerged in salt water, provided the first reproducible and reliable voltage source.

Edison was a firm believer in the advantages of DC power and promoted DC-based power systems for industry and private households. However, inventor Nikola Tesla (1856–1943) made a strong point early on that single-phase AC power (especially triphase current) was an ideal choice for transporting and transforming electricity in a more economic fashion. US-based Westinghouse (AC) and General Electric (DC) fought a long and fierce battle for the dominance of their preferred systems. Some of the first tube designs up to World War II and after were often DC or battery and worked flawlessly.

Until the 1960s, heating and anode/plate batteries featuring mostly 6-V supplies were standard inventory in radio and television stores. During these times, a garden variety of tube radios was popular under the name "all-current-radios."

Depending on local circumstances, these radios could be powered with either direct or alternating power between approximately 100 to 240 V because a standardized power grid was not widely available at the time. During World War II, countless radio operators relied on DC-powered tube amplifiers.

While AC power is now the standard, its triumph certainly did not have anything to do with the unilateral proliferation of DC tube heating systems. In other words, the seemingly eternal question "AC or DC heating?" certainly falls under the category of ideological skirmishes. One thing is certain: Indirectly heated vacuum tubes with DC-powered heaters eliminate or at least greatly diminish interference by mains hum from the start. The ability to implement a "soft-start" option is certainly a convenience and a welcome bonus. *aX*

Editor's note: This article first appeared in Elektor, *November 2006.*

By Ron Tipton (United States)

Update a Pair of MTX 5i 5.25" Bookshelf Loudspeakers

Replacing drivers produces well-balanced sound

I recently purchased a pair of MTX Audio Monitor 5i 5.25" bookshelf speakers because I needed small monitors for a new computer (see **Photo 1**). I do some audio restoration, so I wanted good sound quality when I wasn't using headphones. I bought these speakers even though several online reviewers mentioned that their midrange frequencies were rather weak.

I used True Audio's TrueRTA Quick Sweep Version 4.0 spectrum analysis software and pink noise to conduct a listening test and make an outdoor measurement. (Quick Sweep is not gated, which means the measurement time is longer than the signal duration. So try to minimize sound reflections into the measurement microphone.)

I used a speaker cable and a microphone cable that run through the wall outside my computer room to measure the loudspeaker performance. I placed the test speaker on a wooden platform about 4' off the ground. I mounted the measurement microphone on a plastic tripod, which I could place up to 30' from the speaker. The graveled ground scattered the noise and minimized direct sound reflections. The microphone was one of a group of three Behringer ECM8000 electret condenser microphones or one of a group of three Dayton Audio EMM-6 electret condenser microphones. With groups of three, you can self-calibrate by comparing microphone pairs. (I used a Tenma 72-7260 sound-level calibrator to achieve absolute calibration at 1,000 Hz.) I used TDL Technology's Model 411 measurement microphone amplifier as a microphone preamplifier.

My test determined that the reviewers were right about the MTX 5i's weakness in the midrange frequencies (see **Figure 1**). I wasn't content to just examine the overall frequency response, so I decided to dig deeper.

TESTING THE ORIGINAL

I disassembled one of the units and removed the 5.25" woofer, which I suspended in free air. I used Dayton Audio's WT3 woofer tester (which was recently replaced by the Dayton Audio Test System) to measure its Thiele-Small values with Dayton Audio's WT3. I measured Vas with the added-mass method.

I measured the box dimensions and then used Harris Technologies's BassBox 6 Pro simulation software to model it as an unfilled, vented enclosure. I also measured just the woofer in the vented box. **Figure 2** shows the simulated and measured responses. Except for the peak at about 150 Hz, the curves are not very similar, but I think the measured response is more reliable. The 150-Hz peak and the 500-Hz dip are at least partially responsible for the weak midrange (more about that later).

The simulation indicated that this woofer was equally suited for both a vented or sealed box. I removed the vent in the simulation and produced the curves shown in **Figure 3**. The sealed-box curve is for heavy acoustical fill because this provided

Photo 1: These are the MTX Audio Monitor 5i bookshelf speakers before they were updated.

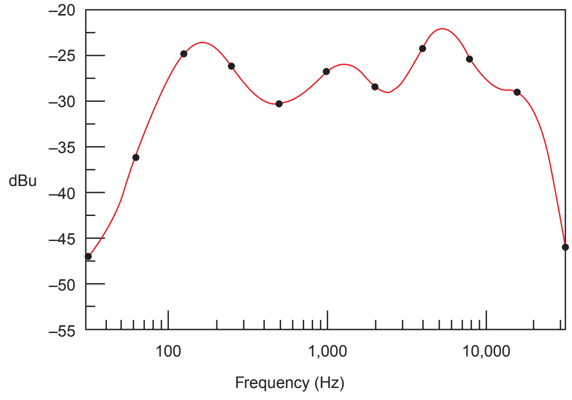

Figure 1: My test documented the MTX 5i's weakness in the midrange frequencies. This 1-octave bandwidth analysis used TrueRTA Quick Sweep software.

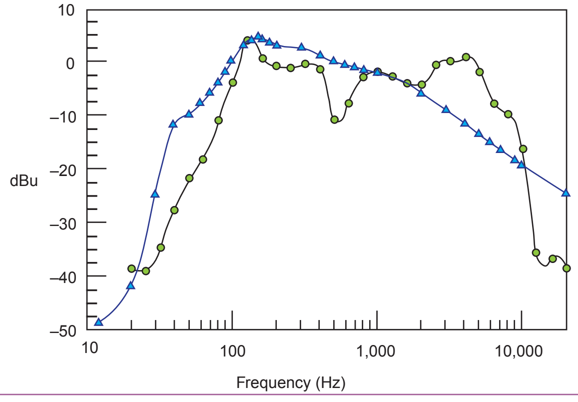

Figure 2: The frequency response of the original MTX 5i woofer in a vented box (green circles) is compared with a simulated response (blue triangles) using BassBox 6 Pro software. I used TrueRTA Quick Sweep software for the measured response (green circles). Except for the 150-Hz peak, the curves are not similar.

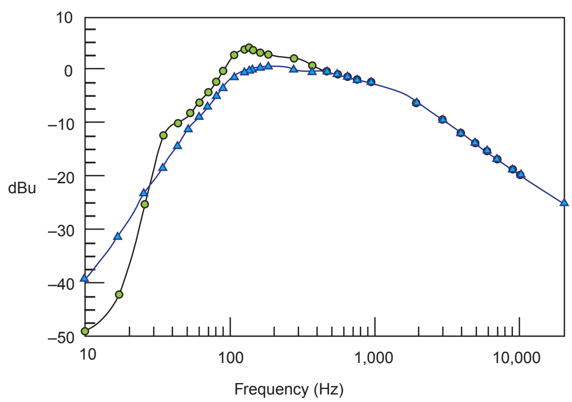

Figure 3: The BassBox 6 Pro software simulation uses the upper curve (circles) to show the results of the original vented enclosure. The lower curve (triangles) is with the vent sealed and heavy acoustical fill.

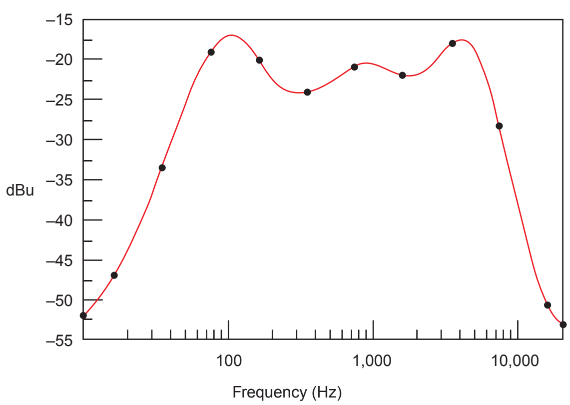

Figure 4: The original MTX 5i woofer's frequency response in the sealed port box with no acoustical fill shows the dip at about 500 Hz is still there. The 1-octave band-width analysis used TrueRTA Quick Sweep software.

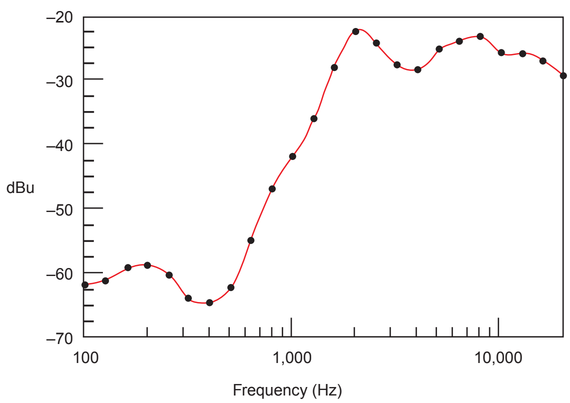

Figure 5: I measured the original MTX 5i tweeter's fre-quency response. The third-octave bandwidth analysis used TrueRTA Quick Sweep software.

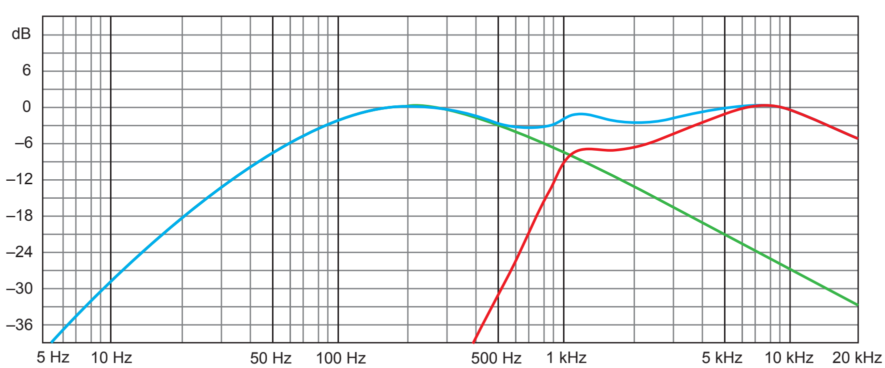

Figure 6: This shows the BassBox 6 Pro simulation of the updated MTX 5i with the Dayton woofer and tweeter. The woofer is the green line, the tweeter is the red line, and the overall response is the purple line.

the lowest closed box Q measurement (0.887), indicating that this box is a bit too small. A larger sealed box would have a Q closer to the 0.707 maximum flat value. But, as expected, the sealed box response is flatter at the expense of a higher rolloff frequency.

I sealed the box and measured the response to determine if the dip would still be there. The vent tube was lightly glued into the box front and is easily popped out with a broad, wood chisel. I glued a piece of 0.125″-thick pressed board over the vent opening and used a hobby knife to remove the thin vinyl box covering under the "patch," so the glue would adhere to the medium-density fiber board (MDF). **Figure 4** shows a frequency response measurement. The dip is still there.

The tweeter is a 12-mm balanced dome with specifications unknown to me. The crossover is a 3.9-μF capacitor in series with the tweeter's inductance and DC resistance. So this is a first-order network with a 6 dB per octave rolloff and a calculated 10-kHz corner frequency. I removed the capacitor and measured the response (see **Figure 5**). It was not especially flat, and this—along with the first-order crossover network and the absence of a reasonably flat woofer—convinced me to update the drivers. I wanted to keep the boxes because of their size and appearance.

DRIVER UPDATE

For my first task, I needed to choose a new pair of fairly well-matched drivers. So, I turned to the Parts Express catalog to see what I could find. I chose Dayton Audio's DC130A-8, a 5.25″ woofer, which is a "drop-in" replacement for the original, and Dayton Audio's ND28F-6 neodymium dome tweeter. The tweeter is a 1.125″ unit and is not a direct replacement, but it is close and it is easy to drill new mounting holes. The original's mounting-hole circle diameter is 59 mm, while the replacement's mounting hole is 56 mm. I turned the new tweeter 90° and connected it to a portion of the MDF that did not already have holes.

The Dayton datasheets provided the T-S values for both drivers, so I used the Xover Pro passive network design program to simulate the design

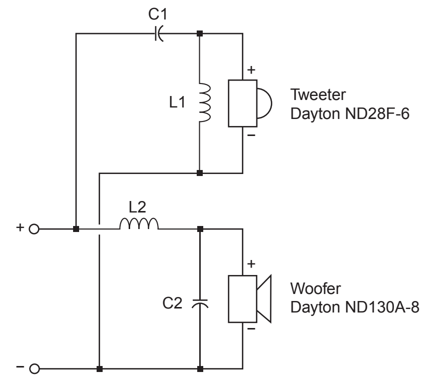

Figure 7: This circuit diagram shows the 2,200-Hz Linkwitz-Riley crossover network.

in BassBox. A 2,200-Hz, second-order Linkwitz-Riley network provided a nice overall response (see **Figure 6**). **Figure 7** shows the crossover circuit. Component values are calculated for an 8-Ω woofer and 6-Ω tweeter. C1 is an Audyn Cap Q4 series 2.7-μF 400-V crossover capacitor in parallel with an Audyn Cap Q4 series 3.3-μF 400-V crossover capacitor, 5% value tolerance (Parts Express part numbers 027-111 and 027-112, respectively, or their equivalents). C2 is an Audyn Cap Q4 series 4.7-μF 400-V crossover capacitor, 5% (Parts Express part number 027-114 or equivalent). L1 is a Jantzen Audio 0.85-mH air core inductor, 3% (Parts Express 255-244 or equivalent). L2 is a Jantzen Audio 1.2-mH air core inductor, 3% (Parts Express 255-254 or equivalent).

THE CONSTRUCTION

I sealed the vent port on the second box and stained both patches ebony black to match the vinyl covering. I built the crossover on a Parts Express model 260-130 crossover two-way PC board. **Photo 2** shows a completed network, which measured 3.75″ × 5.5″. The liberal use of hot glue is suggested as is the "brace" for the vertically mounted inductor. It's a short length of 0.5″ × 0.75″ MDF, and I included it because I mounted the network board on the inside back of the box using four #6 × 5/16″ sheet metal screws. With both drivers out of the box, there really is enough room to do this!

Photo 3 shows the completed rebuild and **Figure 8** shows the measured outdoor response. The rebuilt speakers have a flatter response than the original unaltered MTX 5i, but the proof is in the listening.

LISTENING TEST

I compared the rebuilt speakers with my pair of Tom Simmons Memorial Design Number 2 line-array speakers (see **Photo 4**). Each of these speakers has nine 3″ Tang Band drivers in a 40.5″ tall sealed enclosure. The frequency response is ±4 dB from 100 Hz to 20 kHz. I didn't use a subwoofer because I thought it would distort the test.

I listened to three CDs presenting a variety of musical styles. I used these music sources for the listening tests: Diana Krall, *The Girl in the Other Room*, Verve Music Group Super Audio CD (SACD), 2004; Mozart Clarinet Concerto K622, Michelangelo Chamber Orchestra, Music Fidelity SACD,

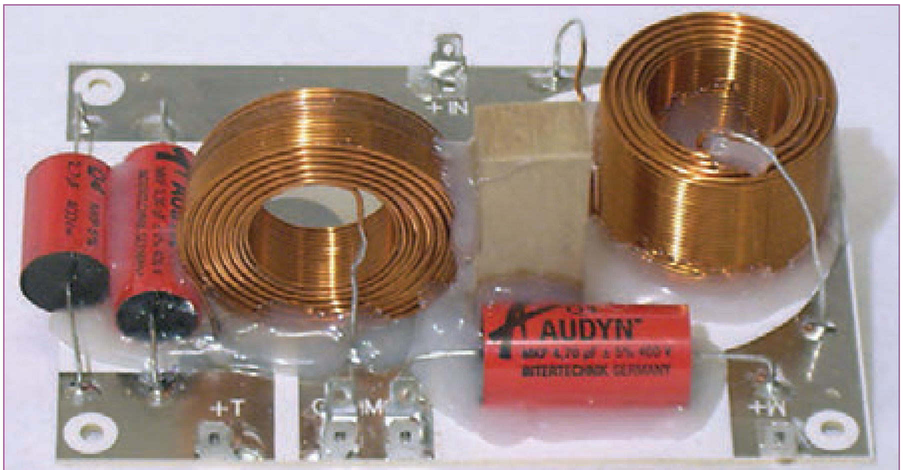

Photo 2: The completed crossover network measures 3.75″ × 5.5″. The two inductors are mounted to minimize cross coupling.

Photo 3: This is the completely rebuilt MTX 5i, showing the new drivers and the patch covering the vent hole.

number MFSACD017, 2004; and Bill Evans Trio, *Waltz for Debby*, HDTracks.com download, DVD-Audio.

When I first started listening, the MTX 5i speakers sounded terrible, with lots of hangover on transients. But this disappeared when the speakers started to break in 30 min later. After a couple of hours, they sounded good. They were bright but well balanced with a nice transient response. I thought the drum-kit sounds, in particular, were more live than the line arrays. Perhaps the dome tweeter has a better high-frequency response than the array. I don't have data on either one above 20 kHz. The line arrays, of course, had a much bigger sound stage and were perhaps more "mellow" by comparison. But both speaker sets were equally pleasant.

The comparison equipment started with a Pioneer DV-563A DVD player's output into one stereo channel of a TDL Model 457 Audio Control Center. One 457 stereo output channel drove an Ed Simon Class A power amplifier and the line arrays. Ed Simon's describes his original design for the Class A Ed Simon power amplifier in his article "A Solid-State Single-Ended Power Amp" (*audioXpress*, April 2006).

I built this amp twice: First as described and then as a rack-mount version. The file at www.tdl-tech.com/simon.zip contains my notes, circuit diagrams, circuit board layouts, photos, and a SPICE model with the required library files.

A second TDL 457 output channel drove a Ferretti power amplifier and the MTX 5i speakers. (Marco Ferretti described his power amplifier in his *audioXpress* article, "A Modular Hybrid Amp System," February 2001.) This hybrid uses a vacuum tube input and a solid-state output for the best of both worlds.

I used the TDL 457 channel selection to easily switch between speaker pairs. The TDL 457 also has individual channel volume controls, so I could set up the speakers for equal loudness. I swapped the power amplifiers part way through the test without any change in my impression of the rebuilt MTX 5i speakers. The listening room is 17′ × 28′, and I listened from 21′ back midway between the left and right speakers.

Figure 9 shows the original and updated MTX 5i speakers' group delay comparison. It is generally thought that a flatter time delay has less distortion. This is another trade-off that a vented enclosure makes for its extended base response.

FINAL THOUGHTS

Was this rebuild worth it? Yes, I think so. But it depends on your interests and capabilities. For example, it would have cost me less to build the sealed enclosures than it did to buy the original speakers. But, I have a rather complete workshop and have

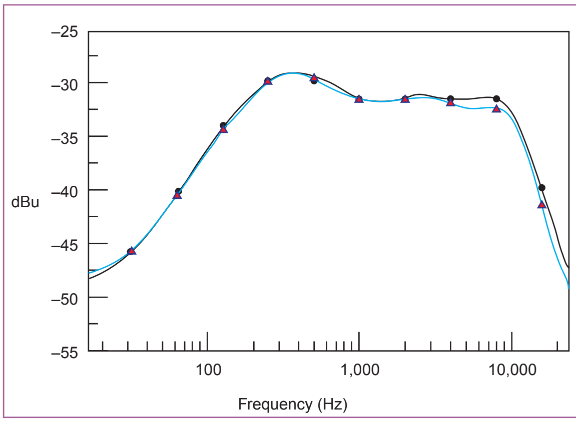

Figure 8: This 1-octave band analysis shows the updated MTX 5i's measured frequency response. The upper line (circles) is the response without the front grill. The lower line (triangles) is with the front grill in place. The grill attenuates the higher frequencies by about 1 dB.

Photo 4: This listening test setup includes a partial view of one of the nine-driver line arrays. The right and left speakers are about 18′ apart.

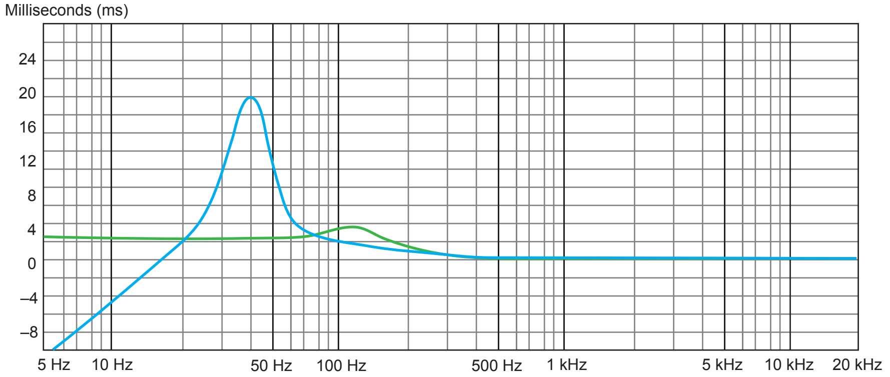

Figure 9: This shows the group delay comparison of the original and updated MTX 5i speakers, utilizing the BassBox 6 Pro simulation software. The peaked response (blue line) is the original vented MTX 5i. The nearly flat line (green) is the updated speaker.

built several speaker systems. If you don't have a woodshop or the building experience, then I think you will get a much superior set of speakers by doing the update. *aX*

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ECM8000 Microphone
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EMM-6 Electret condenser microphone, DC130A-8 woofer, and ND28F-6 neodymium dome speaker
Dayton Audio | www.daytonaudio.com

BassBox 6 Pro loundspeaker simulation software
Harris Technologies, Inc. | www.ht-audio.com

Tenma 72-7260 Sound level calibrator
MCM Electronics | www.mcmelectronics.com

260-130 Crossover two-way PC board and Jantzen Audio 0.85-mH and 1.2-mH air core inductors
Parts Express | www.parts-express.com

TrueRTA audio spectrum analyzer software
True Audio | www.trueaudio.com

By George Ntanavaras (Greece)

A High-Quality, High-Power Headphone Amplifier

Design is based on superior op-amps used in audio applications

Headphones have an important advantage over loudspeakers. They completely remove the room acoustics, which makes them an ideal tool for speaker designers. A high-quality pair of headphones reproducing a well-known recording can serve as a reference when evaluating a newly designed loudspeaker. Of course, a high-quality amplifier must drive high-quality headphones. This article describes the design and construction of a high-quality, high-power headphone amplifier (see **Photo 1**).

Photo 1: The completed headphone amplifier has a clean and simple design.

DESIGN OBJECTIVES

When built, I wanted the amplifier to deliver at least 1 W_{RMS} at 32 Ω. This meant the amplifier must have 5.7-V_{RMS} output voltage, which is more than enough to drive any headphone to its maximum sound level. I wanted all the amplifier's components, including the power supply (with the exception of the transformer), to be placed on a single PCB for ease of construction. The amplifier needed a volume control so it could be directly driven from the analog output of a CD/DVD player, a phono preamplifier, or any other analog source.

The amplifier also needed to be used as a high-quality line preamplifier. The amplifier design is based on high-quality op-amps used in audio applications.

THE AMPLIFIER'S DESIGN

Figure 1 shows a simplified block diagram of the headphone amplifier. The design consists of three main blocks: the amplifier circuit, the power supply, and the protection circuit. **Figure 2** shows the amplifier's complete electronic schematic. The schematic only shows one channel, however, the other channel is identical.

The amplifier circuit includes the volume control, the gain amplifier, and the output buffers connected in parallel. The circuit's first section is the RF filter for electromagnetic interference (EMI) protection, consisting of R9 and C3. These components create a low-pass filter at about 340 kHz. The previous stage's output impedance can lower the low-pass filter's corner frequency. So, if this impedance is greater than 500 Ω, the capacitor C3 should be decreased accordingly to prevent excessive high-frequency loss.

Next, there are three pins to connect the volume control potentiometer, which is on the amplifier's front panel. The volume control's position at the input protects the amplifier's next stages from any possible overload. I used an Alps Electric 100-kΩ stereo potentiometer for the volume control.

I used the capacitor C4 for the DC protection of the following circuitry. This is the only capacitor used in the amplifier's audio signal path. I needed resistors R14 and R38 to ensure a DC path for the circuit's proper operation.

The first part of the IC1 consists of a noninverting gain stage for the amplifier and it also drives the next circuit. For this position, I used a Texas Instruments OPA2134 op-amp, which is a low-noise, ultra-low distortion amplifier especially designed for audio applications. As indicated in the schematic, I set the gain to about 7.5 dB. This enabled the amplifier to fully drive most headphones.

But, be careful! If the amplifier's

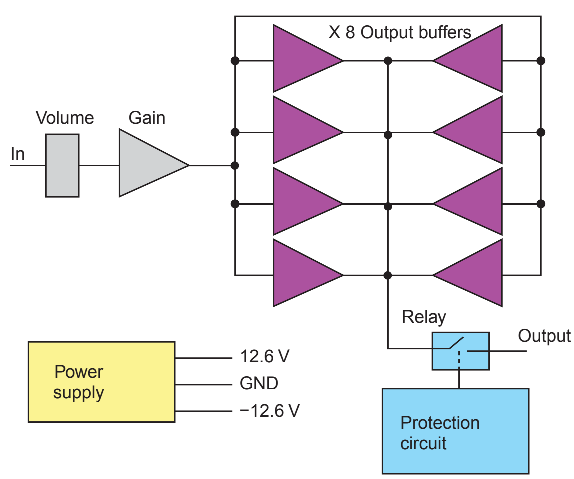

Figure 1: The headphone amplifier includes an amplifier circuit, a power supply, and the protection circuit.

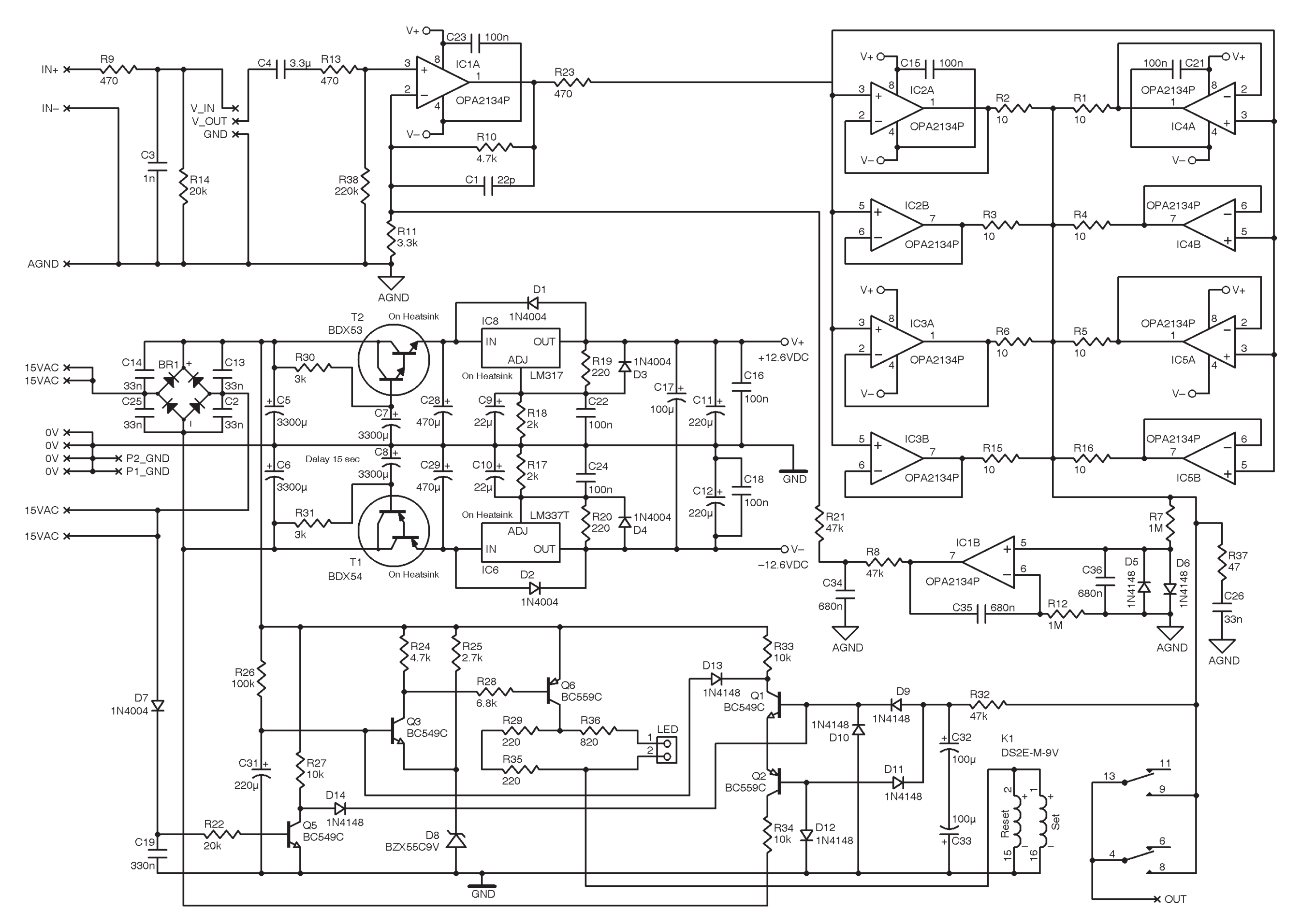

Figure 2: The headphone amplifier's electronics are built around a Texas Instruments OPA2134 op-amp.

volume is left at its maximum value when the amplifier's input is directly connected to a CD or DVD player's output (which means a full signal of 2 V_{RMS}), the amplifier's output voltage could blow out your headphones and perhaps your eardrums. It is safest to always power up the amplifier with the volume set to its minimum position.

If your headphones are sensitive, you may want to reduce the gain. This can be done by increasing the value of R11. The output circuit consists of eight op-amps working as voltage followers with their outputs connected in parallel by 10-Ω resistors. I chose the OPA2134 op-amp for this position for the same reasons I previously mentioned and also because it can drive 600-Ω loads at a full output voltage. Each OPA2134 op-amp's output current capability is 35 mA, according to the datasheet. So, the amplifier's total output current capability is 280 mA peak (i.e., 8 × 35 mA). With a 32-Ω output load, the amplifier's total output power capability is 1.25 W! The output voltage required for this power is 6.34 V_{RMS} or 9-V peak, which is within this circuit's capabilities.

The components R37 and C26 at the output help stabilize the amplifier's high-frequency behavior when driving long cables or difficult loads. The circuit around IC1B is a noninverting DC servo integrator, which keeps the amplifier's output at 0 V and eliminates any DC offsets of the circuit. Using the servo circuit also eliminates the need for a capacitor in the amplifier's feedback loop.

I used an additional R-C low-pass filter consisting of R8 and C34 at the servo op-amp's output to completely attenuate any noise that might be driven to the amplifier's more sensitive first stage.

THE POWER SUPPLY

A 15-VA power transformer provides the required 2 × 15 VAC for the amplifier's power supply. A 2-A/100-V bridge rectifies the AC voltage to DC voltage and charges the two 3,300-µF capacitors. The capacitors C2, C13, C14, and C25 in parallel with the rectifier diodes reduce their noise.

The next stages with components around transistors T1 and T2 are classical capacitance multiplier stages. I used large-value capacitors (C7 and C8), which significantly attenuated the ripple voltage before it came to the LM317 and LM337 regulators. I adjusted the output voltage for each side to 12.6 and –12.6 V, accordingly.

The output bypass capacitors C11, C12, C16, C17, and C18 further improve the regulators' stability. I used diodes D1, D2, D3, and D4 to prevent the capacitors from discharging through low current points into the regulators. This protects the regulators from any possible damage.

The transistors (T1 and T2) and the regulators (IC6 and IC8) required some heatsinking to avoid high temperatures. I used isolators to screw them to an aluminum square rod (see **Photo 2**). I then screwed the aluminum rod to the amplifier's chassis. This was more than enough to keep them cool even when driving the maximum power.

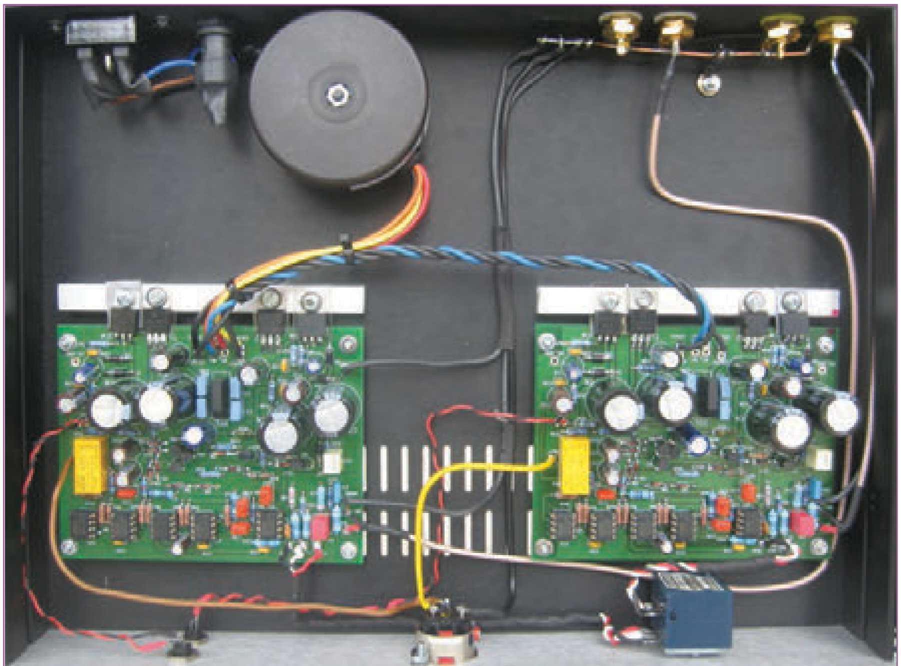
Photo 2: The headphone amplifier has a simple internal construction.

PROTECTION CIRCUIT

The protection circuit is based on a 1999 *Electronics World* article by Douglas Self, which supports several basic functions. During the amplifier's power-on, it connects the output with a delay to avoid any transient noise. It quickly disconnects the output during the amplifier's power off or if a power loss happens. It continually senses the amplifier's output for DC voltages and quickly disconnects the output if there is any DC fault. This will protect the headphones if something goes wrong with the amplifier.

CIRCUIT OPERATION

When power is applied to the circuit, the components D7, C19, R22, and Q5 detect the presence of the 50-Hz line voltage and the transistor Q5 is set to the On status so the diode D14 is shorted to the ground. This prevents the circuit's activation around Q1 and Q2. The relay K1 is turned on with the RC constant's delay of R26 and C31.

The Zener diode D8 generates a 9-V constant voltage, which is used in conjunction with the capacitor C31's voltage for the output relay's activation. The capacitor C31's voltage is increased slowly by the R26-C31 constant. When it reaches about 9.5 V, the transistor Q3 is activated, which turns on the transistor Q6, activating the relay K1.

Any DC output offset at the output is sensed by the circuit around transistor Q1 and Q2 with the help of the diodes D9, D10, D11, and D12. The components R32, C32, and C33 create a low-pass filter at a very low frequency so the protection circuit cannot be activated by the output signal's strong bass frequencies. The transistor Q1 detects the positive DC voltage and the transistor Q2 detects the negative voltages. When the voltage

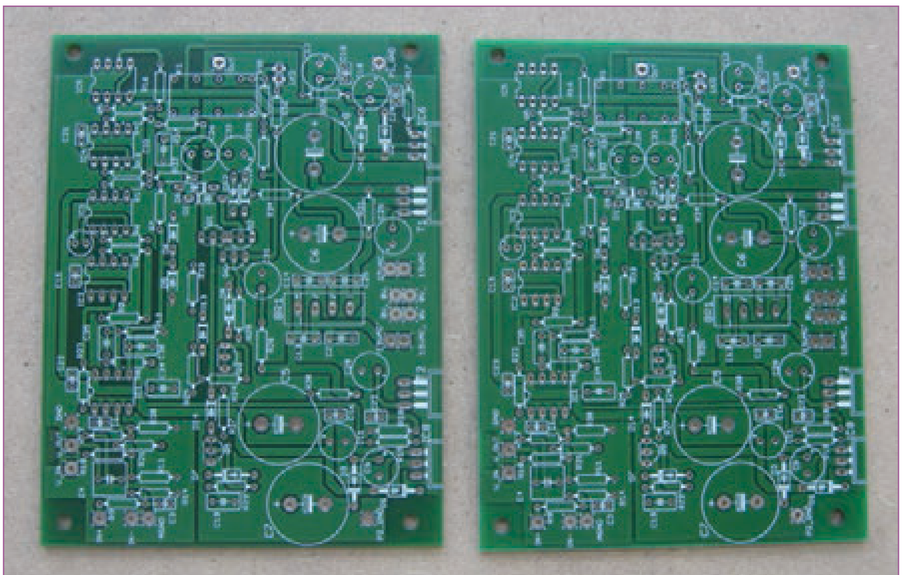
Photo 3: The stereo amplifier's construction requires two PCBs.

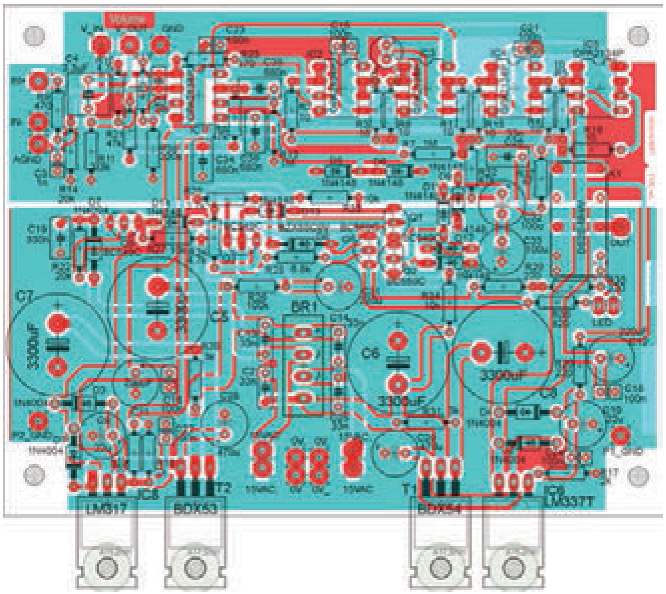

Figure 3: The amplifier's PCB assembly shows that the amplifier's signal ground and power supply ground are not connected to it to avoid ground loops problems.

is greater than about 2 or −2 V, the transistors Q1 or Q2 are activated and the relay K1 is deactivated quickly disconnecting the output. The LED is in series with the output relay. When the LED is illuminated, it indicates that no fault is detected by the protection circuit and the output is normally connected.

AMPLIFIER CONSTRUCTION

As previously mentioned, one of my design objectives is to have all the amplifier's components on a single PCB, simplifying its construction. I used a demo version of CadSoft's Eagle PCB software for the design. The program limited the PCB's maximum dimensions. The outcome was a 90-mm × 115-mm double-sided PCB with ground planes on the top and bottom layers. Each PCB has the components for only one channel, so I needed two PCBs for a complete amplifier.

Photo 3 shows the PCBs I used. These are high-quality PCBs with board material FR4 of 1.6-mm thickness and 35-µm copper. They also have plated through holes, solder resistance on both sides, and a silkscreen on the top side.

Figure 3 shows the PCB's complete guide assembly. The parts list shows what is required to build one channel. To construct a complete amplifier, double the parts list.

To avoid ground loop problems, the amplifier's signal and power supply ground are not connected on the PCB. They should be connected together at a common point near the signal input ground.

I used a metal enclosure with a 10-mm aluminum front panel to house all the amplifier's components. The enclosure had the following dimensions: 340 mm (width) × 5 mm (height) × 240 mm (depth). The amplifier's front panel has two LEDs on the left side, one for the left channel and the other for the right channel to indicate the amplifier's normal operation.

In the panel's center is a 0.25" metal jack for the amplifier's headphone output. I used a Neutrik NJ3FP6C socket,

Headphone Amplifier Parts List

(for one channel)

All resistors are 0.25 W, 1%, except as noted

Part = Value

Capacitors
- C1 = 22p
- C3 = 1n, MKT
- C4 = 3.3 µF, MKT
- C5, C6, C7, C8 = 3,300 µF, 25 V
- C9, C10, C17 = 22 µ, 63 V
- C11, C12 = 100 µF, 35 V
- C31 = 220 µF, 25V
- C2, C13, C14, C25, C26 = 33 n
- C15, C16, C18, C21, C22, C23, C24 = 100 n
- C19 = 330n
- C28, C29 = 470 µ, 25 V
- C32, C33 = 100 µ, 16 V
- C34, C35, C36 = 680 n

Miscellaneous
- K1, Relay = DS2E-M-9V
- LED
- Transformer = 2 × 15 V/15 VA

Resistors
- R1, R2, R3, R4, R5, R6, R15, R16 = 10 Ω
- R7, R12 = 1 M
- R8, R21, R32 = 47 kΩ
- R9, R13, R23 = 470, 0.1%
- R10 = 4.7 kΩ, 0.1%
- R11 = 3.3 kΩ, 0.1%
- R14, R22 = 20 kΩ
- R17, R18 = 2 kΩ
- R19, R20, R29, R35 = 220 Ω
- R24 = 4.7 kΩ
- R25 = 2.7 kΩ
- R26 = 100 kΩ
- R28 = 6.8 kΩ
- R30, R31 = 2.7 kΩ
- R27, R33, R34 = 10 kΩ
- R36 = 820 Ω
- R37 = 47 Ω
- R38 = 220 kΩ

Semiconductors
- BR1, Bridge rectifier 2KBP = 2 A/100 V
- D1, D2, D3, D4, D7 = 1N4004
- D5, D6, D9, D10, D11, D12, D13, D14 = 1N4148
- D8 = BZX55C9V
- IC1, IC2, IC3, IC4, IC5 = OPA 2134
- IC6 = LM337T
- IC8 = LM317T
- Q1, Q3, Q5 = BC549C
- Q2, Q6 = BC559C
- T1 = BDX54
- T2 = BDX53

which is a high-quality socket with silver contact plating and a 10-A current rating. It has a locking capability that requires users to press a red button to release the headphone plug. The volume control sits on the front panel's right side. I used an Alps 100-kΩ stereo potentiometer. The aluminum knob is chromium plated for a nice appearance.

I used Front Panel Express's Front Panel Designer to create the text on the front plate. I used my ink-jet printer to print the front panel information on a transparent, self-adhesive sheet.

I mounted the power transformer as far as possible from the amplifier's electronics parts to avoid any interference. I mounted the two PCBs on the front side of the chassis, near the volume potentiometer and the output connector. The star point ground is close to the amplifer's input sockets. Here, the analog (AGND), the power ground (P1_GND or P2_GND) and the output connector's ground are connected together to the INPUT ground. I used two shielded cables to connect the input sockets and the PCBs. I used twisted cables to connect the volume control potentiometer.

Photo 4 shows the amplifier's back panel. On one side of the panel is an International Electrotechnical Commission (IEC) socket for the 230-V input and the fuse holder. The other side contains four gold-plated RCA phono sockets for the signal inputs and outputs. There is enough distance between them to avoid any interference from the line voltage to the signal voltages. The phono sockets are insulated from the chassis.

For all the amplifier's op-amps, I used high-quality IC sockets with gold-plated pins. This facilitates the testing of the amplifier and the repair in case of any problems.

You should test all the power supply voltages before inserting any op-amp into its socket. The protection circuit should also be tested to check its correct operation when a DC fault appears at the output. This is performed by removing all the output op-amps from their sockets (IC2, IC3, IC4, and IC5) and connecting an external power

Photo 4: The amplifier's back panel shows the in and out connections.

Load	8 Ω	32 Ω	100 Ω	300 Ω
Gain	6.52 dB	7.45 dB	7.6 dB	7.7 dB
Maximum output voltage	1.8 V_{RMS}	6.4 V_{RMS}	7.8 V_{RMS}	8.1 V_{RMS}
Frequency Response	1 Hz to 250 kHz	1 Hz to 250 kHz	1 Hz to 250 kHz	1 Hz to 250 kHz
Maximum output power	0.4 W_{RMS}	1.28 W_{RMS}	0.6 W_{RMS}	0.22 W_{RMS}

Table 1: The amplifier's measurement results were documented as it was consecutively connected to four different resistive loads.

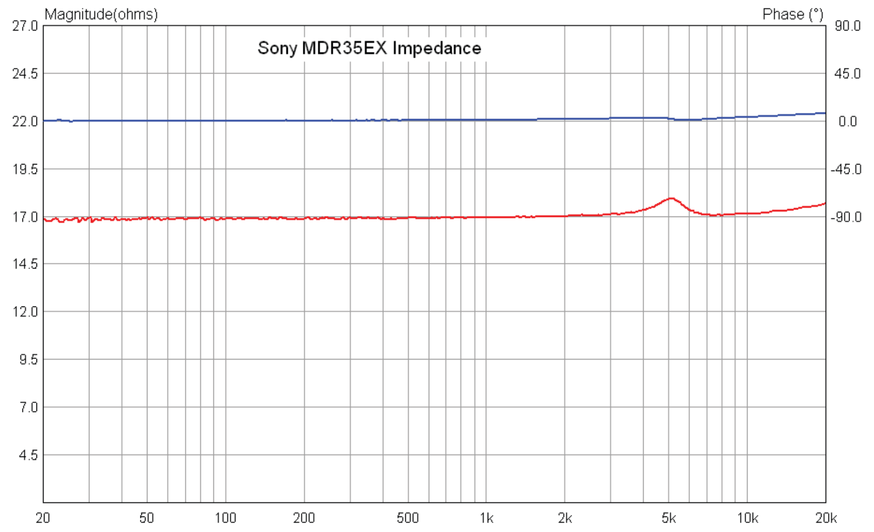

Figure 4: The Sony MDR35EX impedance is almost flat at 17 Ω.

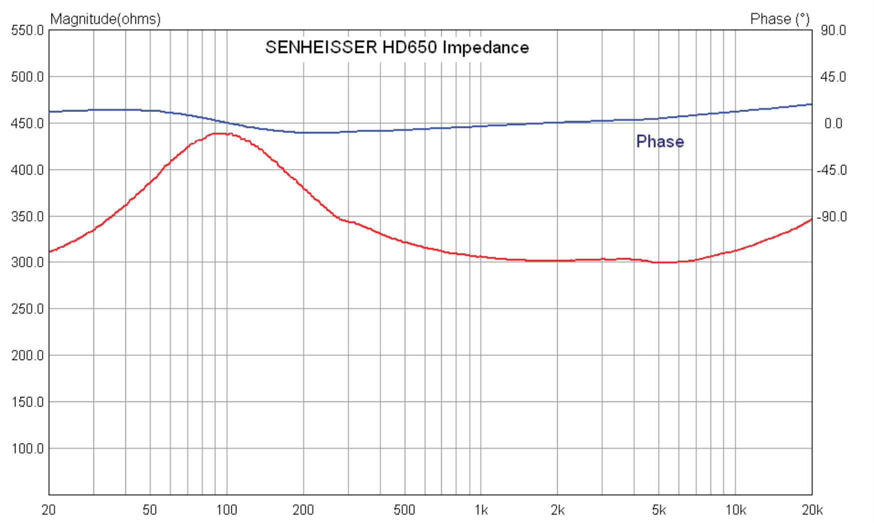

Figure 5: The Senheisser HD650 impedance is flat, close to 300 Ω.

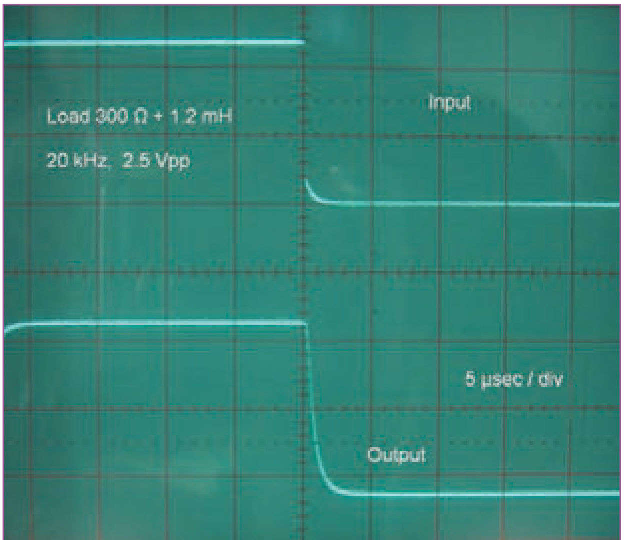

Photo 5: The amplifier response at 20 kHz shows a 2.5 V_{PP} with a 300-Ω load + 1.2 mH (falling).

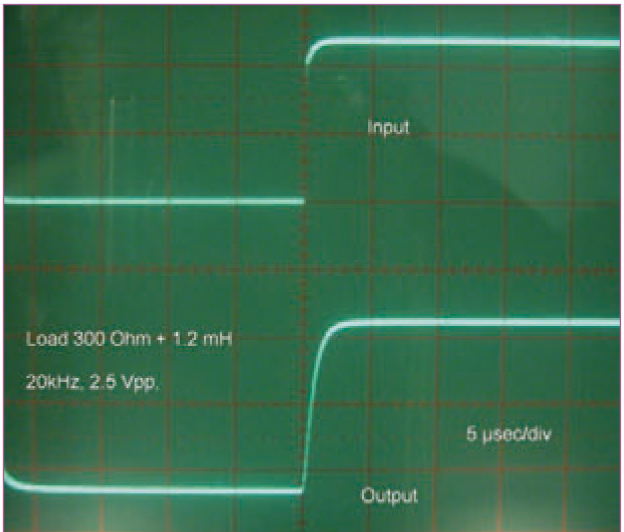

Photo 6: The amplifier response at 20 kHz also shows a 2.5 V_{PP} with 300-Ω load + 1.2 mH (rising).

supply or battery to the amplifier's output. To test it, provide a DC voltage of about 2.5 V first and then –2.5 V directly to the amplifier's output. This should activate the protection circuit relay by disconnecting the output.

AMPLIFIER PERFORMANCE CHECK

After constructing the amplifier, I performed several measurements to check its performance. The headphone amplifier's input was connected to my function generator and the amplifier's output was consecutively connected to four different resistive loads: 8 Ω, 32 Ω, 100 Ω, and 300 Ω. While 8 Ω is not a typical load for a headphone amplifier, I just used it to check the amplifier's capabilities.

For each of the loads, I measured each channel's gain, frequency response, and maximum output voltage just before clipping. I used an oscilloscope to monitor the output voltage (see **Table 1**).

The input impedance is about 15 kΩ. This impedance is easily driven by any CD or DVD player's output. It can be increased, if necessary, by increasing the R14's value. The amplifier's output impedance was measured below 2 Ω. This is a low-output impedance that could easily drive any low-impedance headphones.

To compare measurements, I also wanted to test the amplifier as it was driving an actual headphone load. But I was unable to increase the driving output voltage high enough without damaging the headphones, so I tested it with a simulated load. For this reason, I measured the impedance of two headsets I had available: the Sony MDR-35EX and the Sennheiser HD-650.

Figure 4 shows the Sony MDR-35EX's impedance. It is almost flat at 17 Ω with almost zero phase. Only a very small peak is shown at 5 kHz. So there is really nothing to simulate here.

Next, I measured the impedance of the Sennheiser HD-650 (see **Figure 5**). The test shows a resonance at about 100 Hz with a maximum 440-Ω impedance value. The impedance is flat, close to 300 Ω from about 1 kHz up to 7 kHz, and then it increases to 345 Ω at 20 kHz. The impedance in the range above 1 kHz could be simulated with a 300-Ω resistor in series with a 1.3-mH inductance. I had a 1.2-mH inductor available so I used this for the simulated load.

Photo 5 shows the amplifier's falling response when driving this load with a 20-kHz square wave at a 2.5-V_{PP} voltage level. **Photo 6** shows the amplifier's rising response. This is an excellent response.

EXPECTATIONS MET

This high-quality, high-power amplifier was very easy to construct. It has an excellent transparency, which I consider absolutely necessary to extract the best sound from whatever recording you might hear. Also, it is so quiet that it is difficult to determine whether the amplifier is powered on or off. Finally, it has enough power to drive almost any headphone. *aX*

RESOURCES

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NJ3FP6C Socket
Neutrik | www.neutrik.com

HD-650 Headphones
Sennheiser Electronic Corp. | http://en-us.sennheiser.com

MDR-35EX Headphones
Sony Europe, Ltd. |www.sony.co.uk

OPA2134 Op-amp
Texas Instruments, Inc. | www.ti.com

Editor's note: George Ntanavaras has a small quantity of PCBs (manufactured as shown in **Photo 3***) available for the construction of this amplifier. If you are interested in obtaining one, contact him at gntanavaras@gmail.com.*

Innovator Continues to Test the Limits of Kable

Childhood ingenuity leads to successful business venture

Ray Kimber is the founder of Kimber Kables.

SHANNON BECKER: Tell us a little about your background and where you live.

RAY KIMBER: I live in Roy, UT, a suburb of Ogden, UT. I have always been interested in electronics and audio. In 1955, as a 5 year old, I built a crystal radio kit with help from my father. Then, without any help or permission from my father, I "borrowed" his pair of army surplus communication headphones. Next, I "borrowed" uninsulated craft wire from my mother's hobby box—and for insulation, adhesive bandage tape from the medicine cabinet—and wired it into the crystal set. My father worked as an appliance and electronics repairman, so the kitchen table was always filled with projects and test equipment. I was always right there "helping." The crystal radio kit is long gone now—the victim of too many modifications—but I wanted to be like my dad. So, my interest in audio and electronics, along with my childhood "technical phase," carried into elementary school, scouting, church, junior high, and high school.

SHANNON: How and when did you start experimenting with audio electronics?

RAY: Thank goodness for a rich(er) uncle who had a tape recorder in the 1950s. I was enamored with it. And while I was still in grade school, my father would give me unfixable electronics to tinker with (he supervised the application of power). I literally used baling wire (my grandparents were farmers) to graft a tone arm from one phonograph to another one that had a working motor. During high school I became acquainted with the owner of The Hi-Fi Shop in Ogden. The store carried McIntosh, JBL, Fisher, Dynaco, Thorens, Revox, Shure, Rabco, Ortofon, Sony, and TEAC equipment, among others. He also owned KBOC, a stereo FM radio station—I was in heaven. I worked as a DJ, and I built dozens of kits for his customers.

SHANNON: How did your company Kimber Kable come about?

RAY: In the mid-1970s, I was working as an engineer with a professional audio company in Los Angeles, CA. We had started to design and install equipment in large dance clubs, along with existing studio and commercial projects, and there was a problem with noise. With the advent of disco, the speaker cable was in close proximity to the flashing lights, strobe lights, and neon. Placing the speaker cable in a conduit or other shielding created other problems. I was stumped until I visualized a solution that had the conductors twisting in opposite directions, but with two conductors that wasn't possible. Then, I remembered a Scout craft called Boondoggle. I promptly went to Yale Radio in Hollywood, purchased hook-up wire, and days later had some hand-braided speaker cable. I fully expected it to reject noise, what I wasn't prepared for was the obvious difference in sound. Events brought me back to Utah where I pursued the idea.

SHANNON: What types of products/services does Kimber Kable provide?

RAY: We offer a complete line of speaker cables, analog and digital interconnects, video cables, and power cords. All our products share a familial design structure, but each was designed as a unique "problem solver." Our goals of great products, performance, and value would not be nearly as compelling without the great service and knowledge of the individuals who've made the company possible. Wattgate, WBT USA, IsoMike, and Heatshrink.com are companies under the Kimber Kable umbrella.

SHANNON: In the past 33 years, how has Kimber Kable evolved? What has been your greatest achievement thus far?

RAY: It might be the nontechnical achievement of providing a stable gratifying business for our employees, vendors, and customers.

SHANNON: Can you tell us about your IsoMike demonstrations? How did you start doing them? What do the demonstrations entail? What type of equipment do you use?

RAY: The IsoMike sprang from some curiosity I had regarding series crossovers for loudspeakers. I was curious about how large a space between two microphones would be required before "flanging" would drop to inaudibility if the two microphones were mixed together at the same gain. I then repeated the same experiment but I used gain differential as the factor. Using a sine wave, it turned out to be about a 10′ separation or about 10 dB of differential. However, when using a complex tone, that spacing requirement jumped to about 20′ or about 20 dB. I then concluded that unless a single-point microphone scheme was used, that 20′ plus of separation lowered the flanging effect. But microphones spaced so widely apart would never sound right on a speaker playback (actually they would sound very right and very left, with no center image). Hmmm, I wondered how to make the microphones "think" they were spaced wider than they actually were. I hit on the notion of spacing the microphones at what I considered to be a good width for speaker playback,


The 12TC cable has two 8-AWG conductors. The cable's tonal balance is full, rich, and powerful while the musical impact and dynamics reveal three-dimensionality and imaging.


The PBJ interconnect exhibits simple construction incorporating tri-braid field geometry, VariStrand, Hyper-pure copper conductors, and extruded fluorocarbon dielectric.

about 5′ or 6′, and then developing an absorptive asymmetrical baffle to isolate them.

SHANNON: What do you think is the key to sound done right?


Ray Kimber's IsoMike is an experimental recording apparatus and method used to recreate an original performance in direct-stream digital (DSD) high-definition audio.

A group of musicians rehearse on stage and use an IsoMike to record their audio sound.

RAY: Attention to every detail. You must understand the cost and benefit to each choice in a system. The ability to use both perceived and measured evaluations is also important.

SHANNON: What do you see as some of the greatest audio innovations of your time?

RAY: Radio frequency bending of cabinet materials, cast cabinet materials, astonishingly insightful test and measurement equipment, and direct-stream digital (DSD) have made audio great. Let me use two companies as examples, one relatively under-the-radar and one very well known. Merging Technologies provided the ability to record, edit, and master in DSD and digital eXtreme Definition (DXD). And, Sony for regaining the passion of design and manufacturing in its new SS-AR series of speakers. Audio innovations are great, in part, because of small companies like Merging Technologies with truly great products and Sony, a gigantic company that still has the ability to show soul.

SHANNON: Can you recommend any useful new parts or promising technologies? Is there anything you're currently using that you think readers should know about?

RAY: The newest generation of DACs are delivering greater fidelity for the dollar, and I am delighted that some of them work in DSD. DSD downloads are gaining ground, we have plans to use the service from Blue Coast Records for our IsoMike downloads. And it warms my heart to see new entries in the turntable, cartridge, and phono preamp lineup. Headphones and the associated headphone amplifiers and portable DACs are also enjoying increasing popularity. *aX*

By Richard Honeycutt (United States)

Hollow-State Rectifier Comparison

Vacuum rectifier types, testing, and specifications

The first hollow-state component was the Fleming valve, a low-current vacuum diode that was used as a more sensitive radio detector than the then-ubiquitous Branley coherer. It may seem predictable that the development of higher current rectifier tubes would have immediately followed, but triode development actually took precedence because of the triode's ability to serve as an even more sensitive radio detector. Radios were basically the only commercially important electronic devices of the time.

Because of the limited availability of AC power mains before the late 1930s, most early radio receivers were battery-powered. Thus, there was no great demand for vacuum rectifier tubes. One of the earliest tube rectifiers was the Tungar, developed by General Electric (GE) in 1916 for application in battery chargers. Like most early rectifiers, this was not a vacuum device, but an argon-gas-filled tube. It looked like an incandescent lamp with an anode cap. The development of the vacuum rectifier did not occur until 1925, with British and Dutch manufacturers taking the lead. The type 80 was one of the most commercially successful early vacuum rectifiers.

VACUUM RECTIFIER SPECIFICATIONS

Vacuum rectifiers have five important specifications: filament voltage (which now usually corresponds to the numbers preceding the first letter of the type designation), filament current, peak inverse plate voltage (PIV), peak plate current, and base style. The PIV is the maximum "inverse" voltage that can be applied between the cathode and anode without causing internal sparking (i.e., flashover). "Inverse voltage" is voltage opposed to the polarity of conduction: plate negative with respect to the cathode. This means that the maximum RMS AC voltage that can be safely applied to the tube is 0.707 × PIV. The peak plate current is the maximum instantaneous current the tube can conduct. This current is usually limited by the space charge of electrons released from the cathode.

Vacuum rectifiers are available as a single diode in an envelope (a half-wave rectifier) or as two diodes in the same envelope (a full-wave rectifier). Either type may have a directly or an indirectly heated cathode. An indirectly heated cathode may or may not be internally connected to the filament.

RECTIFIER TYPES

The type 80 is a full-wave rectifier rated at 1,400 PIV and 440-mA peak current per plate. It has a four-pin base with a 4C terminal diagram (see **Figure 1**). Type 80 rectifiers are now mainly used as replacements in antique equipment. More modern rectifiers are available for equipment for which the "B+ sag" provided by a vacuum rectifier is preferred over the better voltage regulation of a solid-state rectifier.

Some of the most common tube rectifiers used in audio power amplifiers comprise the 5U4 family (including the 5U4G, the 5U4GA, the 5U4GB, the 5931/5U4WGB, the 5V4GA, and the 5AS4). These require a 5-V filament voltage at 3 A and use an octal base with a 5T pinout. They are rated at 1,550 PIV and from 525 mA (5V4GA) to 1A (5U4GB and 5AS4) per plate. The industrial/military-type 5R4GYB is rated at 3,100 PIV and 715 mA per plate. It can sometimes be found in used or new old-stock (NOS) condition, and serves well as a replacement for tubes of the 5U4 family as long as the maximum plate current is sufficient. **Photo 1** shows a 5U4G.

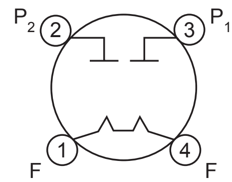

Figure 1: The type 80 rectifier uses a 4C base.

Photo 1: The 5U4G family includes some of the most popular octal full-wave rectifiers.

For lower-power amplifiers, there are two pin-for-pin replacements for the 5U4 rectifier family. The 5Y3GT is a smaller octal full-wave rectifier rated at 1,400 PIV and 440 mA per plate. The 5AR4/GZ34 is rated at 1,700 PIV and 825 mA per plate. One small difference between these two tubes is that the 5AR4/GZ34 has an indirectly heated cathode, which is internally connected to the filament. Because of this difference, the base diagram is numbered 5DA rather than 5T, as for the 5Y3GT and the 5U4 family. In practice, this makes little difference. The 5AR4/GZ34 is usually considered a direct replacement for the 5Y3GT. Both tubes have 5-V filaments. The 5Y3GT draws 2 A, whereas the 5AR4/GZ34 draws 1.9 A.

The nine-pin miniature 6CA4, a lower-current rectifier tube, is shown in **Photo 2**. It is also called an EZ81. This tube, rated at 1,000 PIV and 450 mA per plate, has an indirectly heated cathode that is electrically isolated from the filament as shown in the 9M base diagram (see **Figure 2**). Its filament requires 6.3 V at 1 A.

Photo 2: The 6CA4 is a nine-pin miniature full-wave rectifier.

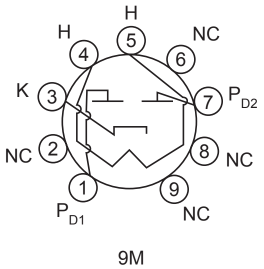

Figure 2: The 6CA4 uses a 9M base.

For circuits requiring less current (e.g., preamps) the octal-type 6X5GT (base 6S) or seven-pin miniature type 6X4 (base 5BS) can be used. These are rated at 1,250 PIV and 245 mA per plate. The 12X4 is identical except that it requires 12.6 V at 0.3 A for the filament, instead of the 6.3 V at 0.6 A required by the 6X4 and 6X5GT.

Hot-chassis circuits with series-string filaments may use rectifier tubes that have higher filament voltages (e.g., the 35W4 octal and the 35Z5 seven-pin miniature tubes). The 35W4 is rated at 360 PIV and 660 mA. The 35Z5 is rated at 700 PIV and 600 mA. Both of these tubes are half-wave rectifiers, and both have an unusual feature. The filament is provided with a tap from which a 7.5-V panel lamp

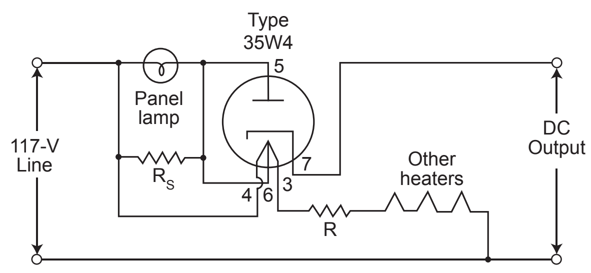

Figure 3: The 35W4 and 35Z5 have pilot lamp taps on their filaments.

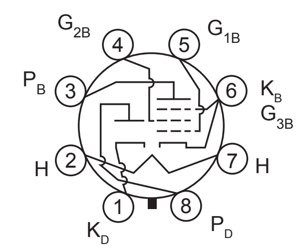

Figure 4: A 70L7 contains a power amp tube and a half-wave rectifier.

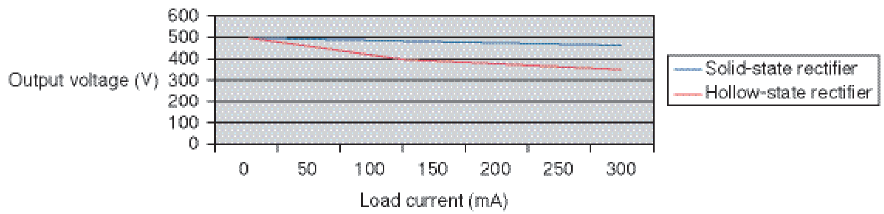

Figure 5: Hollow-state rectifiers' output voltages "sag" more as load current increases.

can be operated (see **Figure 3**).

Figure 4 shows a more unusual tube, the 70L7, which is a combination half-wave rectifier (350 PIV, 320 mA) and 1.8-W beam power tube designed for series-string filament circuits.

SOLID-STATE VS. HOLLOW-STATE RECTIFIERS

As I mentioned earlier, the main performance difference between solid- and hollow-state rectifiers is voltage regulation. **Figure 5** compares the output voltage vs. the current of a solid-state and a hollow-state full-wave rectifier with identical AC input voltages (350 V_{RMS}) and 40-μ filter capacitors. The difference results from the fact that the vacuum rectifier has a higher equivalent series resistance than the solid-state diode. If an amplifier has a vacuum rectifier power supply, the "sag" in B+ voltage at high load currents decreases the amplifier's maximum output voltage. The peak output voltage is not much affected, but loud notes will be "squashed" after a few cycles. Some people prefer this compression of high levels and choose hollow-state rectifiers for this reason.

Many hobbyists decide, at one time or another, to try swapping rectifier tubes in their audio equipment. If you do this, you should take several precautions. First, check a tube manual (or look online) to ensure the basing of the proposed substitute is the same as that of the original. In most cases, it will be the same if the bases are octal, but it is wise to verify. Second, ensure the proposed replacement's PIV and maximum plate current match or exceed those of the original. Third, compare the filament supply requirements. Using a 5U4GB (3-A filament current) to replace a 5Y3GT (2-A filament current) will not immediately blow the power transformer, but it may shorten its life.

Common engineering choices for rectifier tubes include the 5U4GB or its relatives for amps using the 6L6GC or similar power tubes, and the 5Y3GT or the 5AR4/GZ34 for the 6V6GT-class power tubes.

RECTIFIER TUBE TEST

Back in my broadcast-radio-engineering days, my senior engineer

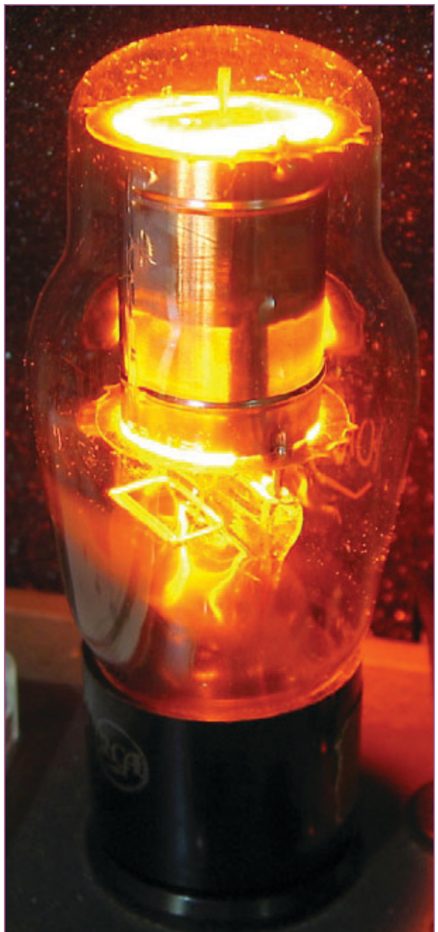

Photo 3: A VR tube illuminates when it is operating.

Tube Type	Voltage
OA3	75 V
OB3	90 V
OC3	105 V
OD3	150 V

Table 1: These are the most common octal-based VR tubes.

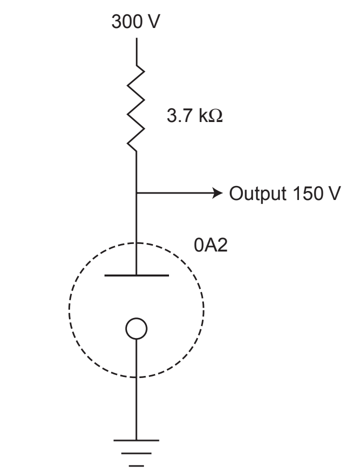

Figure 6: A simple hollow-state voltage regulator uses a VR tube.

Tube Type	Voltage
0A2	150 V
OB2	108 V
OC2	72 V

Table 2: Miniature VR tubes are used in fairly low-current supplies.

taught me a valuable trick for testing rectifier tubes. Rectifier tubes tend to have pretty long lives compared to power output tubes. But there are several ways in which they can die. Of course, the filament can burn out. Usually before this happens, the tube will become "weak" due to the filament having lost some of its metal through evaporation and thereby thinning and developing increased resistance. This causes a decrease in current draw, as a result of which fewer electrons are emitted. The tube then has a higher equivalent series resistance and poorer voltage regulation.

In audio applications, this means there is less output and more distortion from the amplifier being powered by the rectifier. If you use an emission-type tube tester to test the rectifier, set the filament voltage one notch below the rated voltage. A functional rectifier tube will still show good emission under this condition, even though the meter may indicate in the lower "good" range. If the tube is weak, it will show a lower emission. Such an indication reveals that the tube is on the leading edge of causing performance problems and should be replaced.

Another type of tube—not a rectifier, but used in power supplies—is seen in older circuits such as Hammond organs, Leslie organ speaker amplifiers, and some hollow-state commercial audio amplifiers. This is the voltage-regulator (VR) tube shown in **Photo 3**. It has a cold cathode and is filled with a gas that can be ionized by the application of sufficient voltage. When the gas is ionized, the tube's plate-to-cathode resistance drops to a very low value.

The most common VR tubes are the octal-based ones listed in **Table 1**. They can regulate from 5 to 40 mA. In use, a VR tube is connected in series with a resistor. If the supply voltage is higher than the breakdown voltage of the gas, the gas will ionize and the tube will conduct exactly enough current to bring its plate-to-cathode voltage (supply voltage minus drop across series resistor) to the VR tube's precise breakdown voltage. In this way, the voltage across the VR tube is held to a constant value. **Figure 6** shows a partial schematic of the power supply for an audio amplifier using a VR tube.

To properly regulate a voltage, the VR tube must pass some current. Therefore, the total current in the series resistor is the sum of the load current and the VR tube current. If too much load current is drawn, the output voltage will drop below the intended value.

VR tubes are used only in fairly low-current supplies such as for preamp and driver stages. Miniature VR tubes include those shown in **Table 2**. These types can regulate from 5 to 30 mA. There is also a type 85A2 VR tube that can regulate from 1 to 10 mA, providing an 85-V output.

Next month, I'll discuss output transformers. *aX*

By Vance Dickason (United States)

A New Compression Driver with Horn and Two Ribbon Transducers

A quality driver and two tweeters receive rigorous testing

Photo 1: RCF's ND950 1.4" neodymium compression driver along with the HF950 injection-molded composite horn

This is the first time I have been able to examine an RCF transducer. Italian-based RCF has a rich history that extends back to its founding in 1949 by a group of Italian electroacoustic engineers. The company initially made microphones, amplifiers, and related products for public-address applications. However, during the 1950s and 1960s, RCF established itself as an OEM transducer manufacturer. By the mid-1960s, the company had become the first in Europe to have a high-level transducer research center. In 1996, the company launched the ART series of active composite-molded pro-audio cabinets. This technology—used at the time by only a handful of manufacturers in the world—instantly positioned RCF as a global player in the market for pro-audio loudspeakers.

In 2004, a new era began for RCF, with fresh investment in research and development and a renewed commitment to manufacturing in Italy. Since then, the company has designed, put into production, and delivered to the market a substantial number of new products every year. Prominent among them is the TT+ High Definition Touring and Theatre Series, which became an instant success thanks to innovative amplifiers equipped with DSP, along with state-of-the-art transducer technology. Starting in July of 2007, RCF Group (the company that comprises RCF S.p.A. and AEB Industriale, which owns the brand dBtechnologies) was listed on the Italian Stock Exchange.

RCF'S ND950 DRIVER AND HF950 HORN

The driver I received from RCF was the ND950 1.4" neodymium compression driver along with the HF950 injection molded composite horn specifically designed to work with the ND950 (see **Photo 1**). The ND950 uses a 0.05-mm thick pure titanium diaphragm coupled to a flat mylar suspension mounted behind a four-slot phase plug. The throat diameter is 35.5 mm (1.4") with the diaphragm driven by a large 100-mm (4") diameter voice coil wound on a Kapton former with edgewound aluminum wire. Other features include a large neodymium ring magnet, a copper shorting ring, 140-W AES-rated power handling (above 1 kHz), 280 W continuous power handling (above 1.2 kHz), and solderable terminals. The horn supplied with the ND950 1.4" driver is RCF's 1.4" throat 90°-H × 50°-V HF950 constant directivity horn, featuring a 400-Hz cutoff frequency.

I used the LinearX LMS analyzer to produce the 300-point

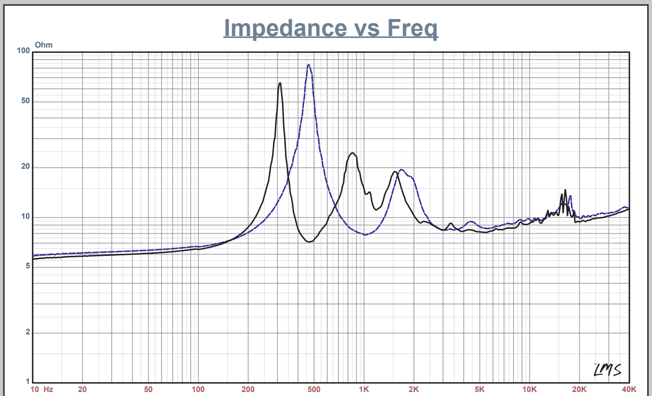

Figure 1: RCF ND950/HF950 free-air impedance plot

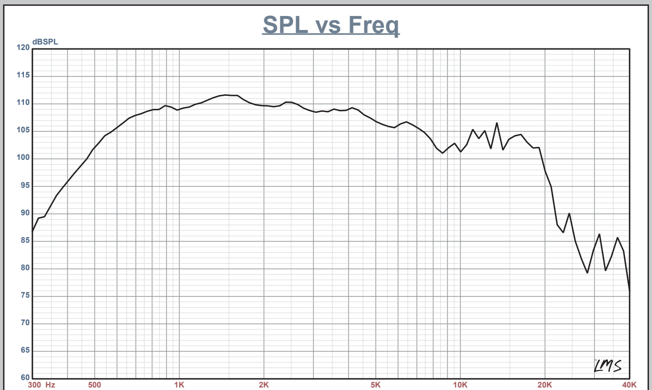

Figure 2: RCF ND950/HF950 on-axis frequency response

stepped sine wave impedance plot shown in **Figure 1**. Note that the solid black curve shows the ND950 mounted on the HF950 horn and the dashed blue curve represents the compression driver without the horn. With a 6.37-Ω direct current resistance (DCR), the ND950/HF950's minimum impedance in the operating range was 8.13 Ω and at 5.5 kHz.

For the next test sequence, I mounted the RCF ND950/HF950 on a rotating platter (no surrounding baffle). I used a 100-point gated sine wave sweep to measure the horizontal and vertical on- and off-axis at 2.83 V/1 m. **Figure 2** shows the compression driver/horn combination's on-axis measurement and an approximate 112-dB maximum

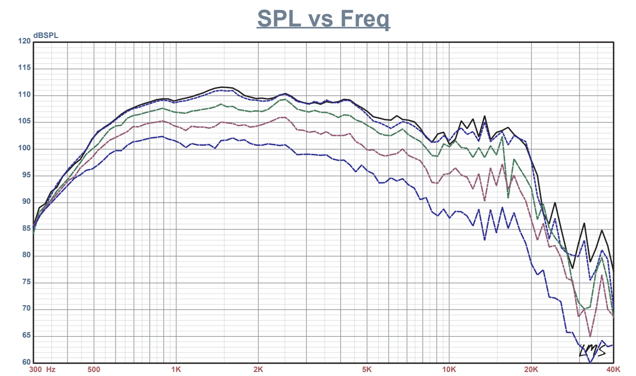

Figure 3: RCF ND950/HF950 horizontal on- and off-axis frequency response (0° = solid black; 15° = dot blue; 30° = dash green; 45° = dash/dot purple; 60° = dash blue)

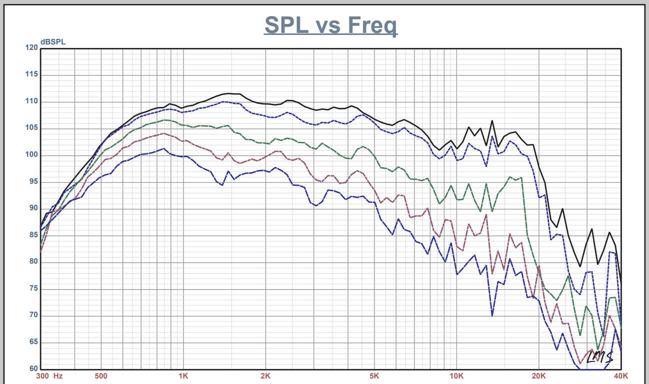

Figure 4: RCF ND950/HF950 vertical on- and off-axis frequency response (0° = solid black; 15° = dot blue; 30° = dash green; 45° = dash/dot purple; 60° = dash blue)

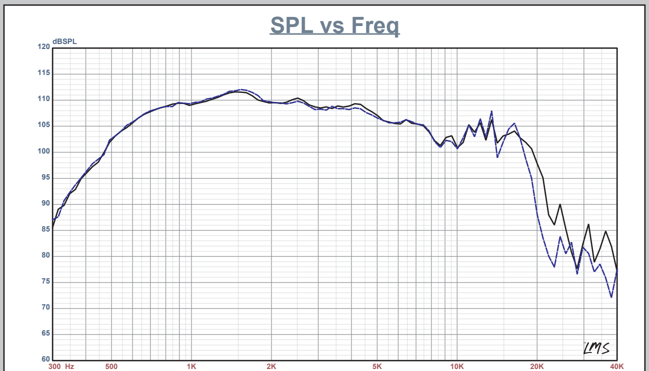

Figure 5: RCF ND950/HF950 two-sample SPL comparison

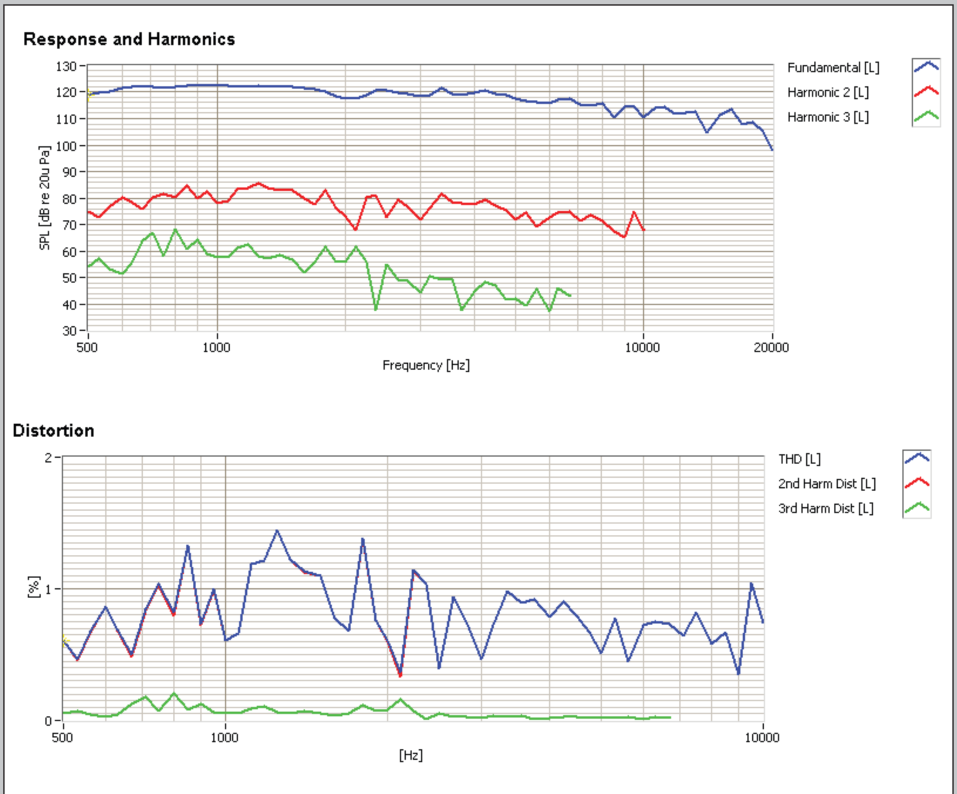

Figure 6: RCF ND950/HF950 SoundCheck distortion plot

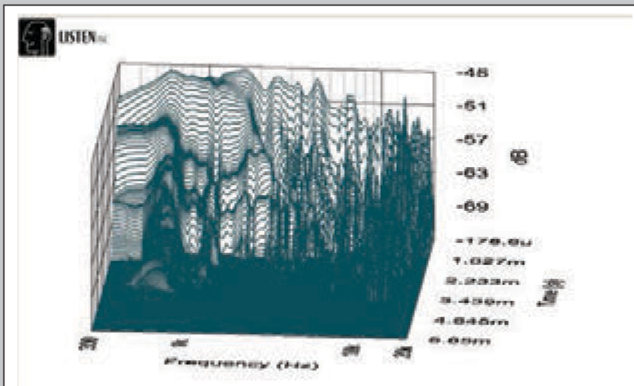

Figure 7: RCF ND950/HF950 SoundCheck CSD waterfall plot

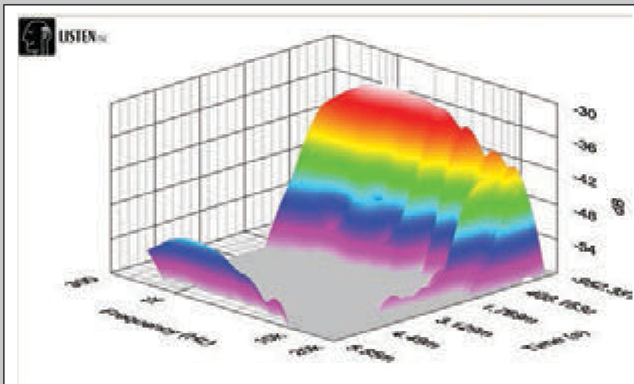

Figure 8: RCF ND950/HF950 SoundCheck Wigner-Ville plot

sensitivity. RCF's rated sensitivity for the ND950 is 110 dB measured with pink noise at 1 W/1 m with a Q of 15 on-axis and averaged between 2 to 5 kHz. The sound pressure level (SPL) profile measures ±4 dB from 550 Hz to 8 kHz.

Figure 3 shows the horizontal on- and off-axis to 60°. The vertical orientation is shown in **Figure 4**. **Figure 5** details the two-sample SPL comparison. Both samples appear to be closely matched.

For the remaining battery of tests, I set up the Listen SoundCheck analyzer and 0.25" SCM microphone and power supply to measure distortion and generate time/frequency plots. For the distortion measurement, I mounted the RCF ND950/HF950 combination on the same rotating platter used for the frequency-response measurements.

I used a pink noise stimulus to set the SPL to 104 dB at 1 m (0.62 V). I measured the distortion with the Listen microphone placed 10 cm from the horn's mouth. **Figure 6** shows the distortion curves this produced. I used SoundCheck to get a 2.83-V/1-m impulse response and imported the data into Listen's SoundMap time/frequency software. **Figure 7** shows the resulting CSD waterfall plot. The short-time Fourier transform (STFT) plot is shown in **Figure 8**.

The RCF compression driver's build quality is impressive, as you would expect from an established pro sound company. For more information, visit www.rcf.it.

THE RT002A RIBBON TWEETER

Next, I analyzed the Beston RT002A ribbon tweeter. Beston Technology was founded in 2002 in Taipei, Taiwan. Since its inception, Beston has focused on high-frequency ribbon devices using a Kapton substrate. The first transducer Beston sent to me for *Voice Coil*'s Test Bench column was the RT002a ribbon tweeter.

The Beston RT002A is a closed-back ribbon tweeter with a 10-mm × 50-mm aperture (see **Photo 2**). Features include a thin laminated aluminum diaphragm, an injection-molded faceplate, a stamped metal chassis, a neodymium (NdFeB) magnet, 40-W rated power handling (third-order 2.5-kHz network), and a pair of solderable terminals.

I began analysis for the RT002A by performing a 300-point impedance curve (see **Figure 9**). Like most ribbon devices, this device exhibits only a slightly defined resonance at 849 Hz (5.5 Ω); however, the impedance is nearly equal to the DCR, which for the RT002A measured 5.3 Ω.

Photo 2: Beston Technology's RT002A ribbon tweeter

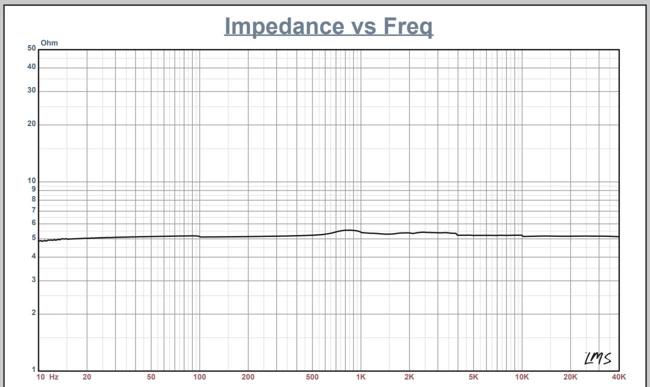

Figure 9: Beston RT002A impedance plot

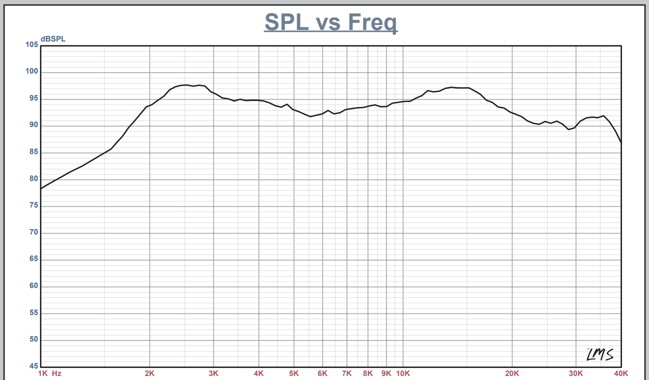

Figure 10: Beston RT002A on-axis frequency response

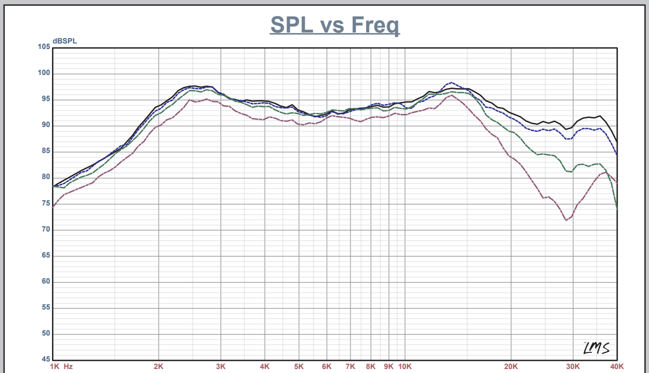

Figure 11: Beston RT002A on- and off-axis horizontal frequency response (0° = solid black; 15° = dot blue; 30° = dash green; 45° = dash/dot purple)

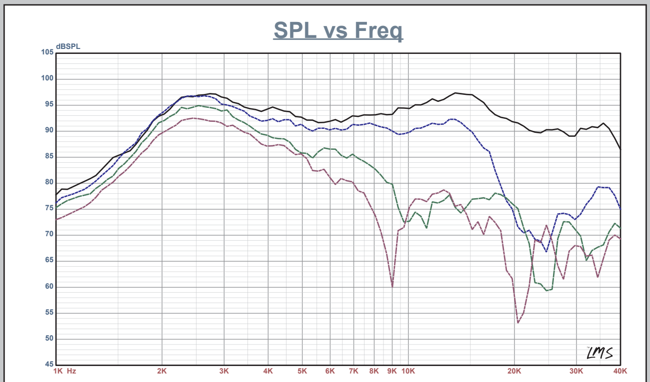

Figure 12: Beston RT002A on- and off-axis vertical frequency response (0° = solid black; 15° = dot blue; 30° = dash green; 45° = dash/dot purple)

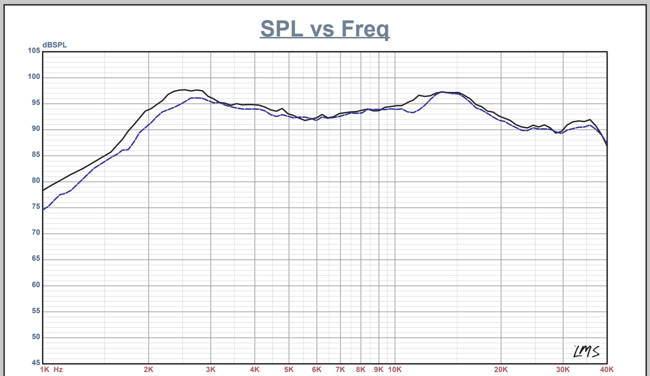

Figure 13: Beston RT002A two-sample SPL comparison

Next, I mounted the RT002A in an enclosure with a 6″ × 12″ baffle area and measured the on- and off-axis SPL. The LMS analyzer was set up to produce a 100-point 2.83-V/1-m gated sine wave sweep from 1 to 40 kHz. (Normally, I set a 300-Hz-to-40-kHz range, but the RT002A was sounding stressed below 500 Hz, which is not uncommon for a small diaphragm tweeter such as this one.) I took data in both the horizontal and vertical planes with sweeps at 0°, 15°, 30°, and 45°. **Figure 10** shows the Beston RT002A's on-axis response. While the factory literature claims a 92-dB 1-W/1-m sensitivity, the SPL in the operating range varied from 92 to 98 dB. The RT002A's frequency response is ±3 dB from 1.9 to 21 kHz with output to nearly 40 kHz.

Figure 11 shows the on- and off-axis frequency response in the horizontal plane, which is excellent. Since the aspect ratio of the RT002A's aperture is pretty extreme (as are many ribbon transducers), there is substantial directivity in the vertical plane (see **Figure 12**). The two-sample SPL comparison is shown in **Figure 13**, indicating that the deviation between the two samples was less than 1 dB from 3 to 10 kHz, with some deviation above and below those frequencies.

For the final measurements, I set up the Listen Sound Check analyzer with the SCM microphone and SoundConnect preamp/power supply (courtesy of Listen). I used the built-in pink noise generator and SLM utilities to set the SPL 94 dB/1 m (0.85 V). I relocated the 0.25″ SCM microphone to 10 cm from

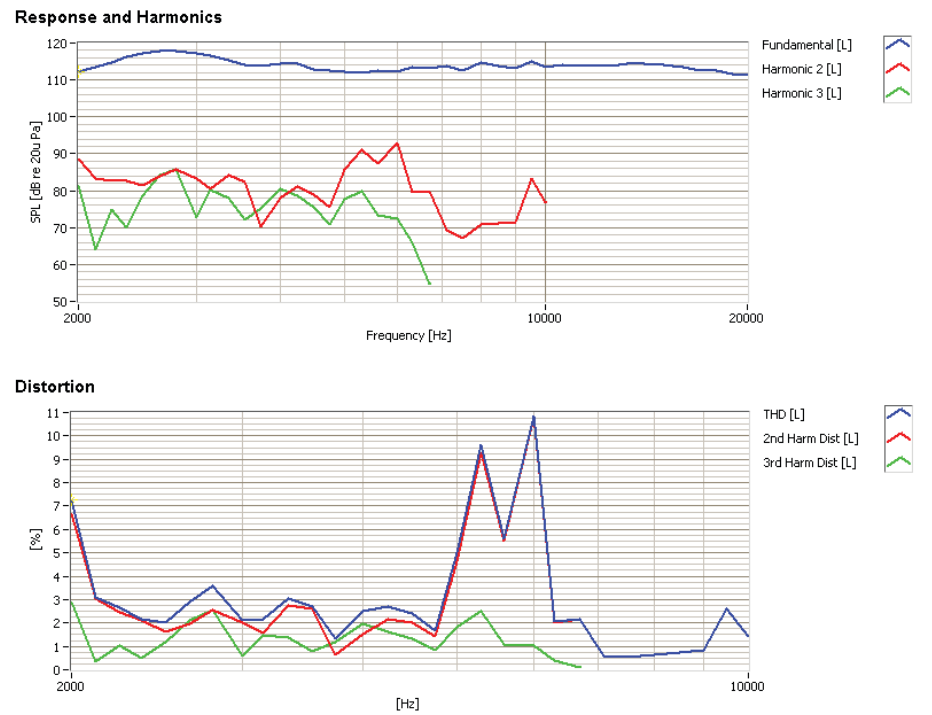

Figure 14: Beston RT002A SoundCheck distortion plot

the Beston RT002A's faceplate and ran the distortion curves (see **Figure 14**). Note that the stimulus was limited to 2 kHz as its lowest frequency.

For the final measurement on the Beston ribbon tweeter, I performed an impulse measurement, then imported the data into the Listen SoundMap software, windowed out the room reflections, and created the cumulative spectral decay (CSD) plot shown in **Figure 15**. The STFT is shown in **Figure 16**. Visit www.ribbonspeaker.com.tw for more information.

THE CQ76 RIBBON TWEETER

Another transducer I tested recently was a new high-end ribbon tweeter from Bozhen New Audio Lab, a Shenzhen, China-based company. Bozhen was founded in 1995 as a high-frequency ribbon manufacturer.

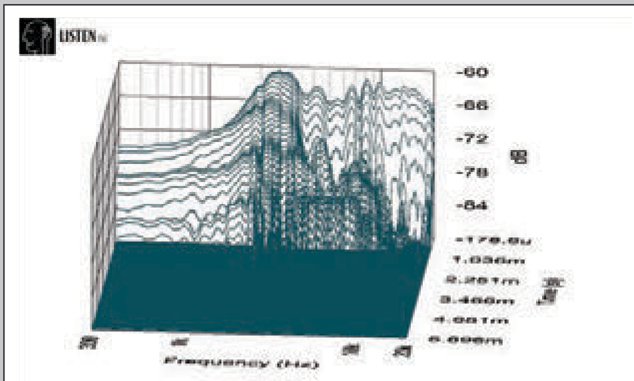

Figure 15: Beston RT002A SoundMap CSD graph

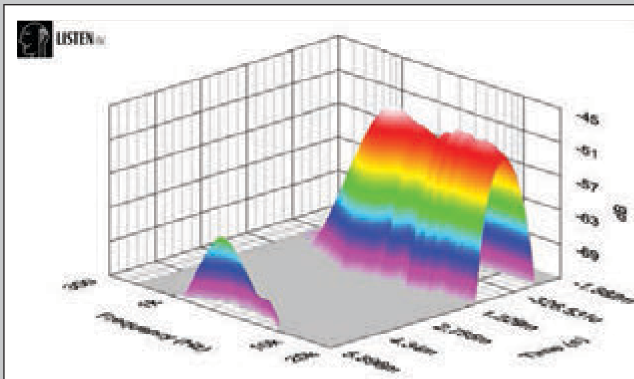

Figure 16: Beston RT002A SoundMap STFT plot

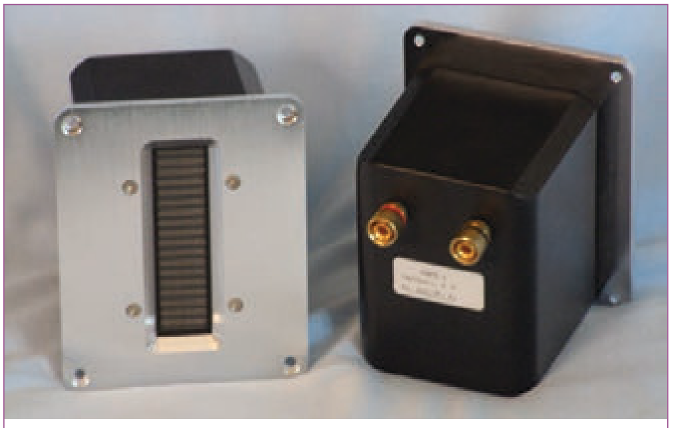

Photo 3: Bozhen New Audio Lab's CQ76 ribbon tweeter

The device Bohzen sent to *Voice Coil*, the CQ76 ribbon tweeter, is portrayed in the company literature as a unique (patent number ZL200820128865.6) ribbon tweeter design, which is visually apparent in **Photo 3**. The CQ in the tweeter's name is an acronym of Chinese pinyin "Chuan-dao-pian Qu-dong," which in English means "ribbon loudspeaker based on slice-conducted technology." Bohzen also makes two other versions of this design: the CQ76-H, a single-ribbon horn-loaded version recommended for high-SPL line-source applications, and the CQ76-2H, a dual-ribbon horn- loaded design.

The CQ76 utilizes a 20-mm × 80-mm pleated aluminum diaphragm making it look like an air-motion transformer without the front-located magnets. The pleats are each

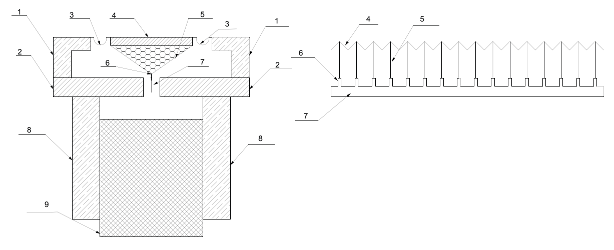

Figure 17: Diagram of Bohzen CQ76's ribbon motor

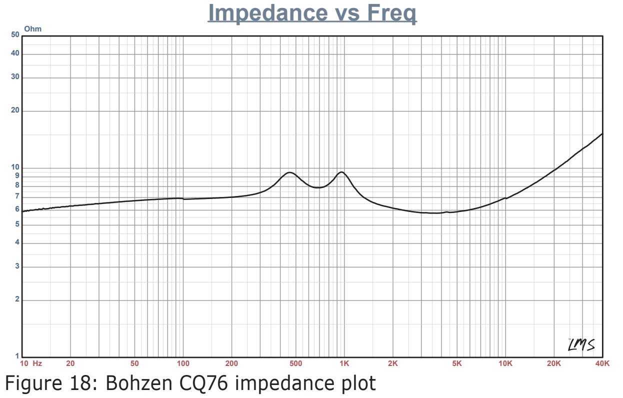

Figure 18: Bohzen CQ76 impedance plot

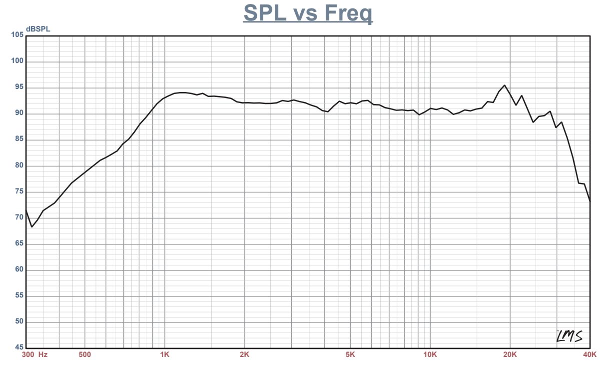

Figure 19: Bohzen CQ76 on-axis frequency response

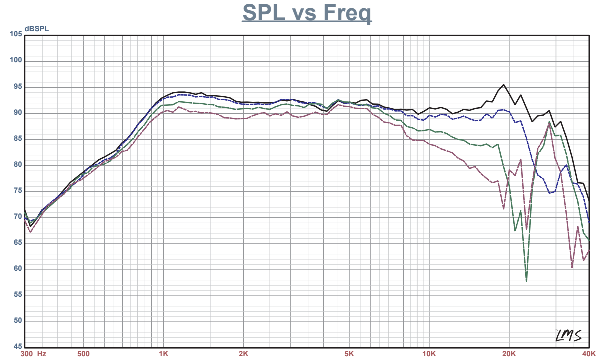

Figure 20: Bohzen CQ76 on and off-axis horizontal frequency response (0° = solid black; 15° = dot blue; 30° = dash green; 45° = dash/dot purple)

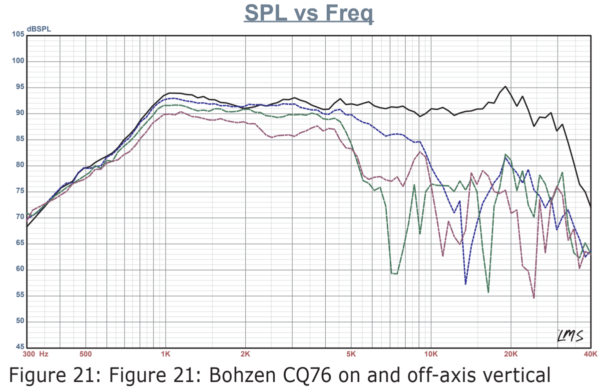

Figure 21: Figure 21: Bohzen CQ76 on and off-axis vertical frequency response (0° = solid black; 15° = dot blue; 30° = dash green; 45° = dash/dot purple)

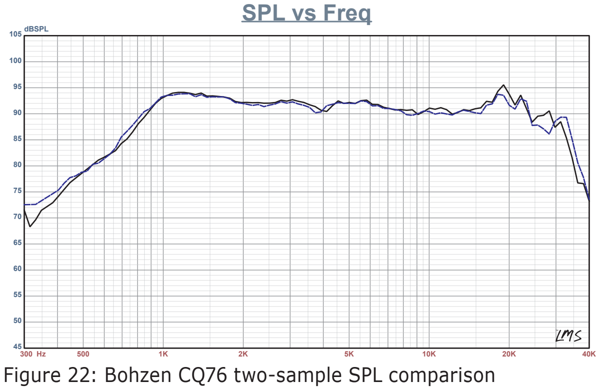

Figure 22: Bohzen CQ76 two-sample SPL comparison

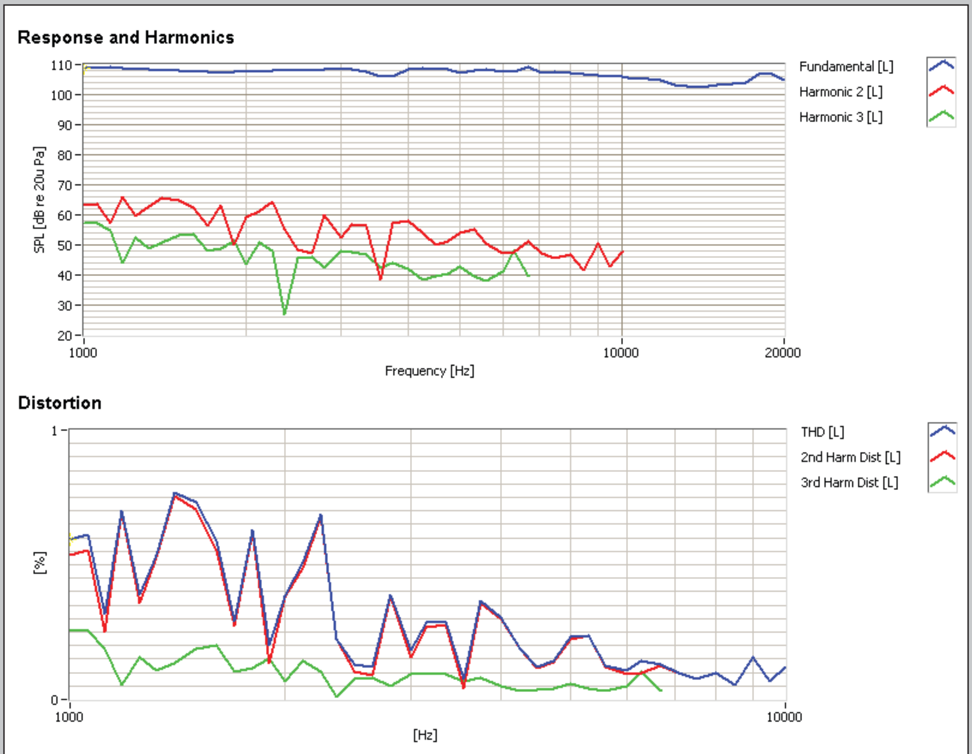

Figure 23: Bohzen CQ76 SoundCheck distortion plot

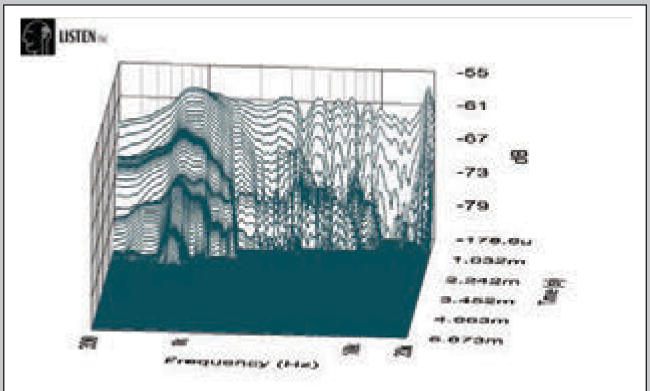

Figure 24: Bohzen CQ76 SoundMap CSD graph

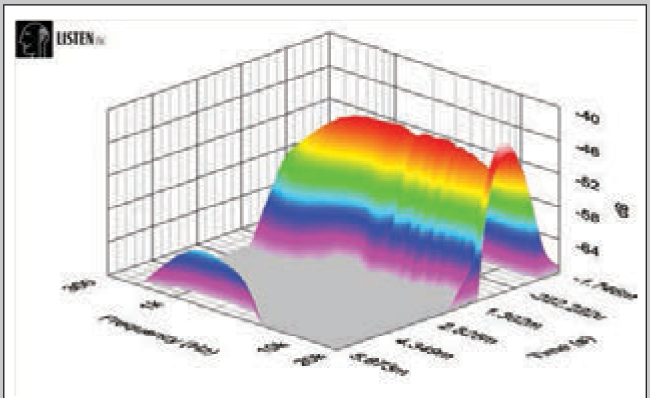

Figure 25: Bohzen CQ76 SoundMap STFT plot

mechanically connected to a section of the voice coil (see **Figure 17**). The CQ76 is a closed-back design that uses a fairly large cavity. Other features for this design include the injection-molded back cavity, a bushed aluminum faceplate, a black mesh screen protecting the diaphragm, and a pair of gold binding posts for terminals.

I commenced the CQ76's analysis by performing a 300-point impedance curve (see **Figure 18**). Unlike most ribbon devices, this transducer's impedance features a twin peak suggesting a complex cavity, plus a reactive rise in the impedance above 4 kHz. DCR for the CQ76 measured 3.6 Ω with a minimum impedance of 4.3 Ω at 3.7 kHz.

Following the impedance measurement, I mounted the CQ76 in an enclosure with a 6" × 12" baffle area. I measured the on- and off-axis SPL with sweeps at 0°, 15°, 30°, and 45° using gated 100-point 2.83-V/1-m sine wave sweeps from 300 Hz to 40 kHz. I took data in the horizontal and vertical planes.

Figure 19 shows the Bohzen CQ76 transducer's on-axis response. The Bohzen CQ76's on-axis frequency response was a smooth and even ±2 dB from 875 Hz to 18 kHz, peaking up to approximately 5 dB at 19 kHz before beginning its low-pass rolloff. **Figure 20** shows the on- and off-axis frequency response in the horizontal plane, which is somewhat like the typical directivity of a 1" dome tweeter. Since the aspect ratio of the CQ76's aperture is like most ribbons, there is substantial directivity in the vertical plane (see **Figure 21**). The two-sample SPL comparison is shown in **Figure 22**, indicating that both CQ76s were closely matched.

For the last batch of measurements, I fired up the Listen SoundCheck analyzer with the SCM microphone and SoundConnect preamp/power supply. I used the built in pink noise generator and SLM utilities to set the SPL to 94 dB/1 m (0.59 V). Next, I relocated the 0.25" SCM microphone to 10 cm from the Bohzen CQ76's faceplate and received the distortion curves shown in **Figure 23**. Note that the stimulus was limited to 1 kHz as its lowest frequency.

For the final measurement on the Bohzen New Audio Lab ribbon tweeter, I performed an impulse measurement, then imported the data into the Listen SoundMap software, windowed out the room reflections, and created the CSD shown in **Figure 24**. The STFT is shown in **Figure 25**. For more information, visit www.bzspeakers.com. *aX*

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VIRTUAL SOUNDCARD GETS AN UPDATE

Audinate recently improved its Dante Virtual Soundcard (DVS) software for Windows. The DVS software enables your PC or Mac to connect your favorite audio application directly to a Dante audio network. DVS uses your computer's standard Ethernet port on your computer to communicate with a network of other Dante-enabled devices—no special hardware is required.

Audinate enhanced its Dante Virtual Soundcard software.

With the new Windows Driver Model (WDM) mode in V3.2.0, DVS for Windows now adds support for applications including iTunes, Windows Media Player, Skype, and more. PC users can play or record audio from these applications with professional sound quality.

Additional features include: a choice of 64 × 64 ASIO or 8 × 8 WDM mode (it presents as four stereo Windows WDM soundcards), a choice of 44.1- or 48-kHz sample rate in WDM mode, Windows 8 32- and 64-bit support, integrated online help, and clock performance improvements. DVS V.3.2.0 is a free upgrade for current licensees.

Download the Dante Virtual Soundcard V3.2.0 for Windows at www.audinate.com/DanteVirtualSoundcard.

E-SERIES A/V RECEIVERS MAKE ENTERTAINMENT MORE ACCESSIBLE

Denon Electronics, a manufacturer of premium home and personal audio products, has launched its E-Series A/V receivers, including the AVR-E400 7.1 Channel Network Home Theater Receiver (SRP: $599), the AVR-E300 5.1 Channel Network Home Theater Receiver (SRP: $399), and the AVR-E200 5.1 Channel Home Theater Receiver (SRP: $249). All three A/V receivers provide new levels of user friendliness, cutting-edge performance benefits, and home entertainment solutions. The AVR-E400 and the AVR-E300 feature Apple's AirPlay, enabling users to stream their iTunes music from a Mac or a PC, and stream music stored on their iPhone, iPad, or iPod touch.

The AVR-E400 and the AVR-E300 add even more network functionality, enabling users to enjoy music from sources such as Pandora, SiriusXM, vTuner, and Spotify, and view photos via Flickr. The AVR-E400 and the AVR-E300 are also compatible with the Denon Remote App, so users can control almost every aspect of their multimedia experience, including browsing Internet radio and files on a media server, playlist creation, volume, input selection, surround-sound modes, and menu navigation

The Denon Remote App enables users to control their multimedia experience.

The new AVR-E400 7.1 receiver provides a surround-sound performance with advanced networking technology and total user flexibility. For example, users can configure the AVR-E400 for a full 7.1-channel system or have a 5.1-channel system in their main room and connect a pair of stereo speakers located in another room. For total system connectivity, the AVR-E400 is equipped with six high-definition multimedia interface (HDMI) inputs including five on the rear panel along with one on the front panel, which enables users to connect an HDMI-equipped camcorder, game console, or other portable multimedia device.

Denon's new AVR-E300 receiver is rated at a maximum of 175 W for each of its five channels and it is equipped with five HDMI inputs including four on the rear panel along with one on the front panel.

The Denon AVR-E200 has a maximum 165-W rating for each of its five channels. The affordable, entry-level AVR-E200 A/V receiver delivers 5.1-channel surround, featuring the latest Dolby and DTS high-definition surround-sound decoding. The HDMI 5.1 receiver also features Denon's Quick Select function, which provides four buttons on the front panel and on the remote control.

Users can also customize the audio parameters for each source with their preferred sound setting. The AVR-E200 is equipped with four HDMI inputs, including three on the rear panel and one on the front panel. For more information, visit Denon's website, http://usa.denon.com.

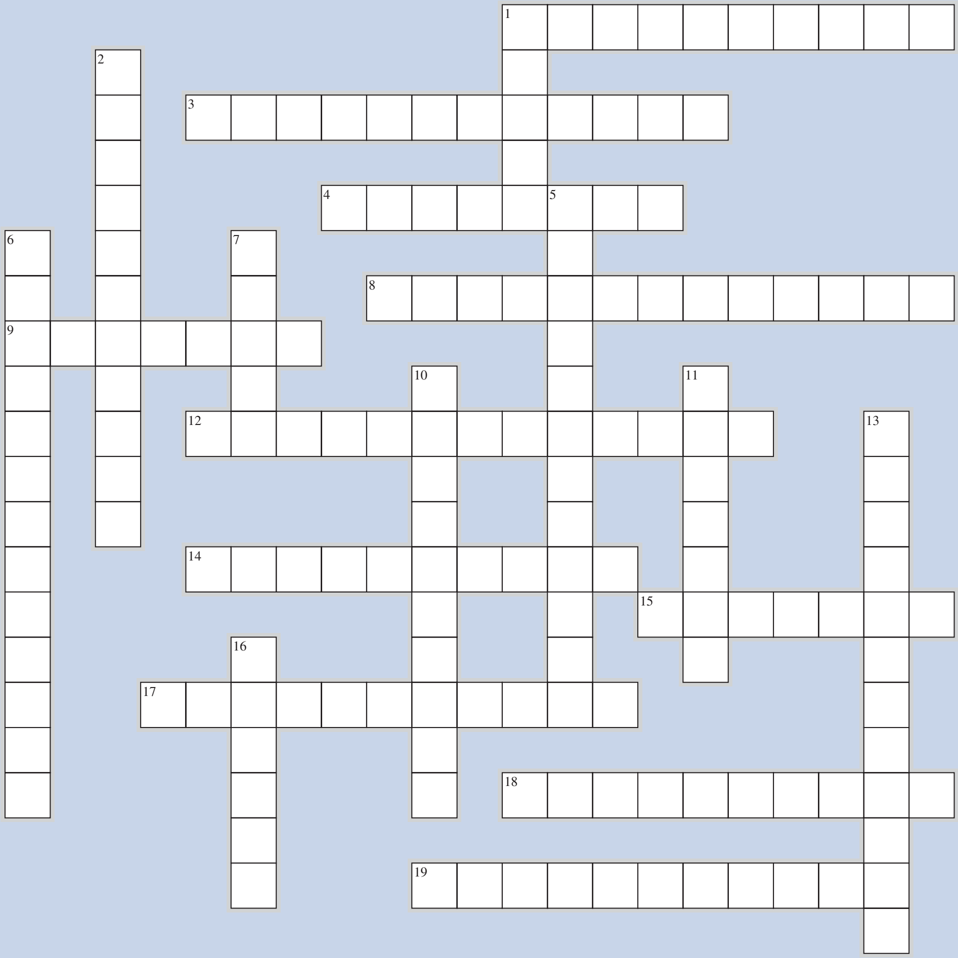
DIGI-KEY SIGNS AGREEMENT WITH GeneSiC

Digi-Key, a global electronic components distributor recognized by design engineers as having the industry's largest selection of electronic components available for immediate shipment, announced an agreement to distribute GeneSiC Semiconductor's silicon-carbide technologies.

Founded in 2004, GeneSiC Semiconductor is a leader in silicon-carbide (SiC) technology. Its products play a key role in conserving energy in numerous high-power systems, running faster, cooler, and more efficiently. This efficiency makes the SiC products ideal for increasing efficiency in energy-harvesting applications.

GeneSiC has the largest commercial SiC diodes portfolio, offering a SiC switch. The super junction transistor (SJT) is expected to revolutionize insulated-gate bipolar transistor (IGBT) and field-effect transistor (FET) designs for engineers who want higher performance. While others have abandoned the silicon, high-voltage rectifier product market, GeneSiC Semiconductor has been investing in new products. GeneSiC Semiconductor's products are available for purchase at Digi-Key's website, www.digikey.com. *aX*

Crossword



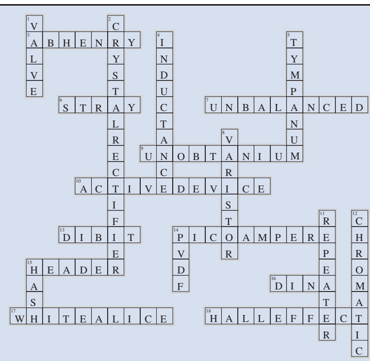
Editor's Note: Answers to this puzzle are posted at audioxpress.com/crossword and will be available in the next issue.

ACROSS

1. Repetitive
3. DIAC [two words]
4. Barrier-grid storage tube
8. Cumulative spectral delay [two words]
9. Coiled material
12. Two outputs created from a single input, one is identical to the original and the other is a mirror image [two words]
14. Uses little electricity and provides a clear flat-screen display [two words]
15. Used in bipolar power-supply transformers to improve output voltage symmetry
17. Inherently omnidirectional [two words]
18. Resistor type that uses a shared collector
19. Voltage applied to a semiconductor's controlling element [two words]

DOWN

1. Converts analog signal to digital and the digital signals back to analog
2. Audio engineer who has contributed to the MPEG Audio Layer 3 audio compression format
5. Eliminates a tetrode's kink [two words]
6. The EL34, the 6CL6, and the 6K6GT are examples of these tube types [two words]
7. It was the early tube's central part. Lead-in wires were fed through and it mechanically supported the electrode system.
10. A true one extends from floor to ceiling [two words]
11. Floor-shaking bass reproduction
13. Needle scratch [two words]
16. Brief transient spike



***audioXpress* did not feature a May 2013 crossword.**
Here are the answers to the April 2013 puzzle.

CONTRIBUTORS

Vance Dickason ("A New Compression Driver and Horn and Two Ribbon Transducers," p. 34) 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, including receiving an AES Citation Award for his ongoing contribution to audio education, he still works as an engineering consultant to a number of loudspeaker manufacturers. This currently includes Samsung, The AVC Group (Niles and Sunfire), Artison, and Emotiva.

Gerhard Haas ("Tube Heating with DC Power," p. 12) lives in Germany and has more than 30 years of experience as a tube amplifier designer. He has written several books on tube engineering. For many years, he owned Experience Audio. He has since retired and in his free time serves as the editor of *Elektor*'s "Tube Specials."

Dr. Richard Honeycutt ("Hollow-State Rectifier Comparison," p. 30) has been an audio enthusiast, musician, recording engineer, broadcast radio engineer (First Class Commercial licensee since 1969), radio announcer, electronics repairman, tube guitar amplifier designer, speaker system designer, pro-sound/video designer, and college electronics teacher. He is now a consultant in acoustics and electroacoustics. He earned a PhD in Electroacoustics from the Union Institute, and lives in Lexington, NC, with his wife, Betty Jane, near his daughter Alyson, her husband, and two of his three grandchildren.

Mike Klasco ("The Air Motion Transformer," p. 8) 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.

George Ntanavaras ("A High-Quality, High-Power Headphone Amplifier," p. 20) graduated from the National Technical University, Athens, Greece in 1986 with a degree in Electronic Engineering. He currently works in the Development Department for a Greek electronics company. He is interested in the design of preamplifiers, active crossovers, power amplifiers, and most loudspeakers. He also enjoys listening to classical music.

Steve Tatarunis ("The Air Motion Transformer," p. 8) 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.

Ron Tipton ("Update a Pair of MTX 5i 5.25" Bookshelf Loudspeakers," p. 15) is a French aero-thermo-mechanical engineer, working as the technical director of a French engineering company. He is involved in the design and setup of large vibration systems and acoustic rooms for environmental tests. His passion for tubes began at an early age, when watching his father repair old radios for their neighbors. He likes to consider new designs proposed by experienced hobbyists and tries to use principles and mathematics to clarify design difficulties. He has been retired since 2008.

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