Amp Uses Affordable Push-Pull Transformer, p. 12

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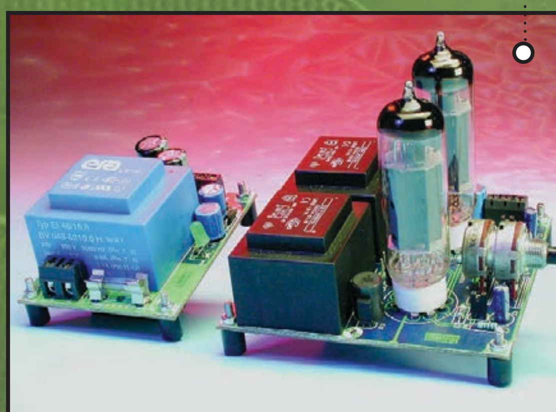

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From the Editor's Desk

What's Your Passion?

Many years ago, a children's book inspired Chuck Hansen's interest in audio electronics. Soon, the clever kid from New Jersey was listening to New York City AM stations on a kit-built radio and disassembling every dead TV and radio he came across—for the parts.

Hansen went on to become an electrical engineer, aerospace industry consultant, patent holder, and author. In an interview on page 27, he discusses his careers and his lifelong enthusiasm for audio projects.

On page 8, Mike Klasco and Steve Tatarunis focus on the piezo ceramic tweeter, in their third installment of "Tweeter Talk." Their article looks at the history and technology of a tweeter that never reached its full potential.

This month's edition also examines the most common subsystem to fail in audio equipment—the power supply. Many things can disrupt it—from electrical surges to lightning. How do you know when power supply problems are causing blown fuses or even a complete shutdown of your audio equipment? On page 32, Richard Honeycutt answers that question and more.

Are you an audiophile who has wanted to work with the FINEMET-core transformer in your own DIY project? On page 12, Tadaatsu Atarashi tells us how he utilized an affordable FINEMET-core transformer in his small output amplifier project.

Turn to page 23 for a look at the Apollon speaker system, designed by German engineer Gerd Lommersum. Utilizing a chassis from the ScanSpeak Illuminator series, the free-standing unit includes a subwoofer that "packs a punch."

In this month's "Test Bench" on page 36, Vance Dickason reviews the 12FHX76 from B&C Speakers, a driver in the company's new line of pro sound coaxial speakers.

Regards,

Mary Wilson
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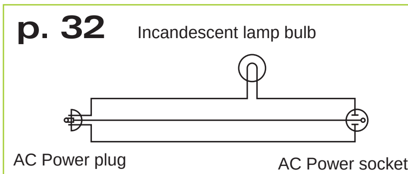

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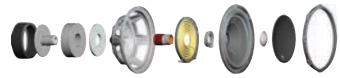
By Mike Klasco and Steve Tatarunis (United States)

Tweeter Talk (Part 3)



The Piezo Ceramic Tweeter

New technology could revive the piezoelectric speaker

Over the next few months, we will continue our exploration of tweeters. We are now moving into the esoteric "weird science" side of tweeters including piezo, air-motion transformers, electrostatic, and polyvinylidene fluoride (PVDF) film. This month, our focus is piezo ceramic tweeters.

PIEZO TWEETER'S ORIGINS

A piezo tweeter contains a piezoelectric element coupled to a diaphragm. An audio signal is applied to the element, which responds by flexing in proportion to the voltage applied across its surfaces, converting electrical energy into mechanical energy. The active element has electrodes attached to two of its opposite faces, and it converts the electrical energy to acoustic energy. We will examine piezo operation later.

In 1999, CTS bought Motorola's Ceramic Group and called its new division CTS Piezoelectric Products. The high-tech ceramic fabrication facility in Albuquerque, NM, remains—everything but the Motorola name on the building was retained by CTS. Piezo development work continued and CTS's innovative new line of piezoelectric inverters (power supply module, not tweeters) was selected as a finalist in *EDN* magazine's Innovation of the Year contest. Perhaps the main reason CTS bought Motorola's ceramic business was for the ceramic inverter technology. At the time, CTS decided the ceramic operation appeared to be well run and, for the first phase, it only moved the speaker final assembly from a Mexican subcontractor to CTS's own speaker production operation in Brownsville, TX.

As unsettling as it is for me [Mike Klasco] to say, I remember more than 40 years ago when Motorola burst onto the speaker scene with its ceramic tweeter technology. From time to time, I did some consulting work for both Motorola and later CTS. About five years after acquiring Motorola's ceramic operation, CTS faced a losing battle. Local North American subcontractors were closing and the tooling CTS inherited from Motorola was wearing out. Menlo Scientific was hired to help the company explore its options, which included moving production operations offshore, selling the product line, or selling the existing inventory. Unfortunately, the piezo's speaker motor structure was based on a polycrystalline lattice structure of the oxides of Lead (P for Pb), Zirconium (Z), and Titanium (T), which came to be known as PZT. With the potential for toxic lead issues—especially in light of new laws like the Reduction of Hazardous Substances (RoHS) Directive on the horizon—CTS decided to end the product line and liquidate the inventory, which brought an end to ceramic speaker development in 2004.

Photo 1: The piezo tweeter contains a piezoelectric element coupled to a diaphragm.

A BIT OF BACKGROUND

In a piezo tweeter, a thin ceramic wafer drives the diaphragm instead of a voice coil and magnetic structure. Unlike previous efforts at piezo buzzers, Motorola developed a "hi-fi" transducer. The core of its technology was its proprietary process for high-density PZT ceramic material (see **Photo 1**). Motorola ceramics were renowned for their consistent high quality and excellent properties. That process remains the industry standard in medical ultrasound imaging and ink jet piezo nozzle printer applications. Likewise, Motorola's piezoelectric tweeters set the standard in the professional sound and autosound aftermarket where ruggedness and reliability are paramount.

The piezoelectric tweeters' moving mass is low so the top-end extends beyond audibility. The impedance drops as the frequency rises—the opposite of the inductive rise of speakers with voice coils. Ceramic transducers are one of few viable solutions for a Super Audio DVD/Blu-ray 40-kHz tweeter. Without a voice coil to burn out or scrape the gap, the technology is highly robust, even if you leave out the crossover network. (Try that on a conventional tweeter!) Motorola's ceramic elements, which CTS later acquired, were fabricated in an automated facility with clean room procedures and workers in protective suits.

The popularity of Motorola's ceramic tweeter products escalated in the 1970s, peaking at more than 7 million units annually in the mid-1990s. At first, Motorola tweeters were successfully used in many fine speakers, from audiophile classics such as Polk Audio's first generation of speakers, and the Dahlquist DQ10, and even the most prestigious professional products from Meyer Sound Laboratories, Apogee Sound, and Community Professional Loudspeakers. Motorola developed unique phase plugs, and horn flares and it even experimented with headsets. Motorola was granted several patents in the early 1970s, but the patent terms began to expire in the 1990s. Endless counterfeit products from China began flooding the market. Anyone who actually tested those initial counterfeit products found the sensitivity, response range, and power handling were dismal, but the price was right and they looked like the real thing—sometimes the products were marked with a counterfeit Motorola insignia!

Eventually, the black plastic horns became too closely associated with the lowest-commodity products and the stock-model designs were phased out of higher-priced speaker systems. But there was also a lot of innovative stuff done with piezo tweeters in the pro market. JBL had a coaxial with a direct radiator piezo tweeter glued to the woofer cone. Peavey Electronics developed a manifold dual-driver piezo horn. Community Audio had an array of three piezo drivers on its fiberglass horn baffle. Even Don Keele, during his brief stay at Klipsch, designed a tweeter line array with five piezo horns as the top end of a full-range theater system decades before line arrays were "in." Prestige brands (e.g., Meyer Sound Laboratories and Apogee Sound) had elegant networks that used piezo to their best advantage. Today, Community Professional Loudspeakers uses piezoelectric technology in its Compact Ribbon Emulators.

When piezo tweeters were good, they were very good. When they were badly used, they were very bad. To make matters worse, the designers of low-end speaker systems typically omitted the crossover network, which did not degrade reliability but the sound quality really suffered. So, the tweeter was blamed even though it was actually bad system design. Now, with mostly counterfeit piezo tweeters being made and the original long gone, the piezo tweeter's reputation has worsened.

PIEZO TWEETER TECHNOLOGY

In operation, the domains within a poled PZT (ceramic) wafer alter their position slightly when an external field is applied. This causes a slight deformation in the wafer's physical geometry. When the field (audio signal) is removed, the wafer returns to its original size. These displacements are small but high in force, and when coupled directly to a liquid or solid medium, they are useful for generating discrete motions. When coupled to air; however, motions of these dimensions are useful only in the ultrasonic region where the acoustic impedance of the air is higher and provides a better match to the PZT. To provide useful motion in the audio region, a "mechanical lever," or transformer, is required to convert the high-force, low-displacement motion to low-force, high-displacement. Cantilevers have been tried, but keeping nonlinearities and resonances can be challenging.

A more common solution is coupling two wafers face to face—especially when the wafers drive a cone loaded by a horn. The wafers are connected such that as one expands, the other contracts. When coupled at their faces with a metal member (center vane), the resulting stress causes the sandwich to dish in and out depending on the applied signal's amplitude and polarity. This "sandwich" is called a bimorph, as it consists of two active piezo elements.

By affixing a cone to the bimorph's center and anchoring the cone at its periphery, the bimorph vibrates synchronously with an applied audio signal and pumps the cone, while pushing against its own mass. In 1970, Motorola developed and patented this concept, called the Momentum Drive Principle. It is the fundamental principle behind a family of speakers introduced in the ensuing 40 years through many technical developments and dozens of patents. NXT's exciters typically use momentum drive (but otherwise completely differ from Motorola speaker operation).

Another interesting aside is Altec Lansing's radial-phase plug was developed after Motorola's super horn phase plug, yet Altec Lansing was issued the patent. We might also mention that Altec Lansing had a "rock 'n roll" home-stereo speaker product line using Motorola's piezo drivers and radial phase plugs with plastic horns—but the horns followed Altec Lansing's Mantaray constant directivity flare.

One piezo tweeter advantage is its high-power efficiency. With no voice coil, there is no resistive heating and little lost acoustical power. In fact, the tweeter's actual impedance is high, from about 50 to 250 Ω. At these values, the amplifier sees little additional load from the tweeter, enabling use of arrays with limited additional power load. Because it generates little wasted energy, it is capable of being driven harder than the dynamic tweeter. Most of this efficiency was not apparent to speaker designers as the ceramic speaker was most often used as a drop-in with conventional amplifiers intended for dynamic speakers.

The piezo tweeter does not require a crossover network. Since the tweeter is capacitive in nature, it rejects low-frequency power. If the midrange is still operating at the tweeter's turn-on (4 kHz, in the Super Horn's case), harshness may be heard in the total system output. Intermodulation distortion (IMD) measurements show that you really want a network in front of the driver, if clean sound is part of your design goals. This disturbance in the crossover region and elevated IMD can be minimized by adding an RC filter tuned to attenuate the turn-on peak, rolling off the midrange a little earlier.

If a conventional crossover network is used, the tweeter must be made to look "resistive" to work with the crossover. This can be accomplished by wiring an 8-Ω resistor across the piezo tweeter. It should be noted that the power-efficiency benefits will be lost since the piezo tweeter will look more like an 8-Ω dynamic unit electrically. However, it will enable the use of conventional crossover technology. If a variable level attenuation is desired, an L-pad can be used.

REFINEMENTS

When the CTS product line ended, there were a half-dozen horn tweeters, a few compression drivers, and four direct radiator tweeters. The KSN1075A direct radiator tweeter offered response to 50 kHz, which interested designers looking for a low-cost, yet robust tweeter solution to compete with wideband DVD/SACD audio. Note: There are several related wideband formats including LPCM (lossless), Dolby HD, DTS HD, and DRA Extension.

In the horn tweeter line, the last crop refined aesthetics with a matte finish and beveled edges, but the changes were not enough. Meanwhile, CTS made an ill-conceived, cost-saving move removing the damping pad from the design, which degraded transient response and smoothness—not something the product line could really afford! The lack of acoustic fuzz in the back chamber cup further exacerbated certain resonances.

THE FUTURE

We don't believe the ceramic tweeter ever reached its full potential. Motorola, and later CTS, limited the product development group's funds, not to mention skimping on the bill of materials (BOM). The diaphragm—highly pressed paper— was also a limiting factor. Actually, the paper formulation and process was special, yet the alternative use

Photo 2: The Linaeum tweeter has a voice coil, which is flattened into a vertical shape and suspended between opposing rectangular magnet poles. (Photo courtesy of Linaeum)

of high-performance diaphragm (e.g., polymer film, aluminum alloy, or titanium) might have provided some benefits. However, the dated cheap black plastic did not do much to enhance the product line's appeal. There are a few specialty applications where PZT speakers remain in use. Some are military, others are music in MRI machines, as the process cannot tolerate any steel construction or stray magnetic fields. The company that bought CTS's remaining parts still assembles a few models using a combination of old parts and new components.

Piezo speakers could be resurrected if they were constructed with optimized electronics and higher-quality diaphragm materials. Refinements to the design execution should include a better damping pad and back chamber fuzz, or even a change in the topology (i.e., do not have the paper cone facing into a plastic phase plug). You may remember the Linaeum tweeters, which were a RadioShack favorite (see **Photo 2**). At one point, Motorola and Linaeum considered a joint development project, combining Linaeum tweeter's topology and Motorola's bimorphs.

CTS still fabricates ceramic wafers but it no longer offers the bimorph back-to-back assembly. What about China ceramics vendors? The conditions in some of China's ceramic factories were unbelievably bad. Workers have been observed shoveling ground lead dust without proper respiratory protection. There are a few Japanese ceramic element manufacturers that offer microspeakers (e.g., the ones used for cellphones) but there is nothing for audio.

JAPANESE ELECTRONICS COMPONENTS

Murata Manufacturing is a large Japanese electronics components company that makes ceramic caps and related components. A few years ago, some of its scientists made a couple audiophile super tweeters, essentially an R&D group's hobby project. Their design, the ES-103 spherical tweeter, incorporated a spherical piezoelectric diaphragm that provides reproduction from 15 to 100 kHz. The ES-103's efficiency is 90 dB/W/m, with an 8-Ω rated impedance, a 50-W (pink noise) maximum power, and ±45° directivity.

The ES-103 is housed in a cylindrical enclosure and is a good fit for big box-type speaker systems (see **Photo 3**). A second super tweeter, the ES-105, has a rounded design that matches modern-style speaker systems and small-speaker systems. The ES-105 uses a zinc-alloy die-cast enclosure, offering excellent damping. To put these super tweeters into perspective, the ES-103A costs $2,250 per pair, the ES-103B costs $2,950 per pair, and the ES-105 costs $1,825 per pair.

Photo 3: The ES-103 incorporated a spherical piezoelectric diaphragm. (Photo courtesy of Murata Manufacturing)

For mainstream speakers, the problem is the heart of the technology, the PZT wafer itself. Until recently, it did not appear there was an alternative to lead use without further loss of needed sensitivity. Lead is a known danger, and while there is, for now, an RoHS exception, enabling PZT speakers to be fabricated, the long-term prospects are not good.

Presently PZT ceramics (e.g., those used in piezo microspeakers and tweeters) are exempted per RoHS Directive 2002/95/EC: Lead in electronic ceramic parts (i.e., Piezoelectronic material) exempted from the requirements of Article 4(1), Section 7. However, this waiver may not continue. The lead is encapsulated but the issues are beyond product-life use. The Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) regulations regarding recycling must also be considered.

THE NEXT CHAPTER

Is it time to close this chapter of speaker technology? Perhaps not just yet. Barium titanate (BNT) ceramics look to be a viable alternative but there does not appear to be a commercial supply for BNT ceramics for speakers. "Recent Progress on Sodium Bismuth Titanate Based Lead-Free Piezoelectric" is explored in a paper written by Dong-Qing Zhang in Piezoelectricity, Acoustic Waves, and Device Applications (SPAWDA), 2008 (ieeeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4775838) available through the Institute of Electrical and Electronics Engineers (ieeeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4775838).

Next month, we explore PVDF high-polymer film and its application with respect to speakers. *aX*

Construct a Four-Parallel 5670W Push-Pull Amplifier

Small triode meets innovative FINEMET-core transformer

Photo 1: This is the completed amplifier's front view.

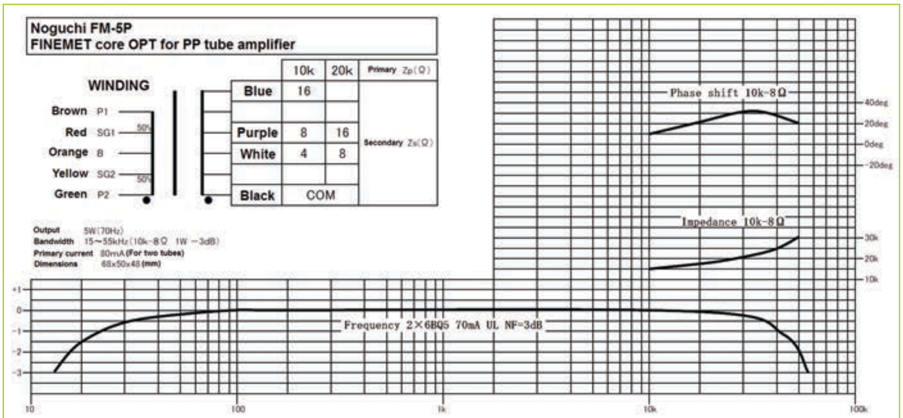


Figure 1: These are the FINEMET-core transformer FM-5P's specifications.

Hitachi Metals has taken the lead in manufacturing nanocrystalline iron-based soft magnetic material, which offers high-saturation flux density, high-relative permeability, and low-core loss. Hitachi Metals registered its product as FINEMET.

Noguchi, a Japanese audio transformer manufacturer, produces a variety of audio transformers especially for tube-amplifier DIYers. It has also offered FINEMET-core audio transformers. I have tried them and the resulting sounds were quite good.

The FINEMET-core audio transformer is renowned among Japanese audiophiles and many audio DIYers want to try it. But the difficulty is the cost. The FINEMET core audio transformers are comparatively expensive. So, many people asked Noguchi to make an affordable one. Recently, the company released its FINEMET core transformer FM-5P, which is a push-pull output transformer that is suitable for a small output amplifier and costs less than $200. I decided to try it in this four-parallel push-pull amplifier project (see **Photo 1** and **Photo 2**).

Photo 2: The four-parallel push-pull amplifier is shown from the side.

The amplifier's primary windings are 10 and 20 kΩ, and the secondary windings are 4, 8, and 16 Ω. The rating is 80 mA through the first winding and 5 W at 70 Hz (see **Figure 1**). The output transformer is not expensive; however, the total cost was almost $400 because two transformers were needed for this stereo application. That meant I had to find savings when selecting other parts.

POWERFUL SOUND FROM THE 5670W

General Electric (GE) produces the 5670W, which is rated five stars and designed as a voltage-gain tube (see **Photo 3**). It is the same as Western Electric's WE396A (2C51). I have often used this tube in my projects and also published some articles on parallel 5670W push-pull amplifiers. The 5670W was designed as a voltage gain tube, but when I use it as output tube, it always sounds powerful. It can rival or surpass general output tubes.

I visited the Classic Components tube shop in Tokyo's Akihabara district and found 10 of the 5670Ws for $85. This price is very inexpensive, considering the WE407A, which is similar to the WE396A but has a 20-V heater, costs $90 in Tokyo.

DESIGN & CONSTRUCTION

Figure 2 shows the schematic diagram. However, the schematic only

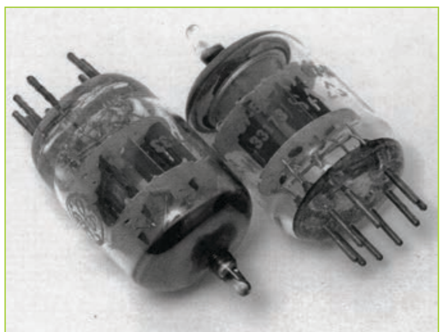


Photo 3: General Electric's small and inexpensive 5670Ws were used in this amplifier.

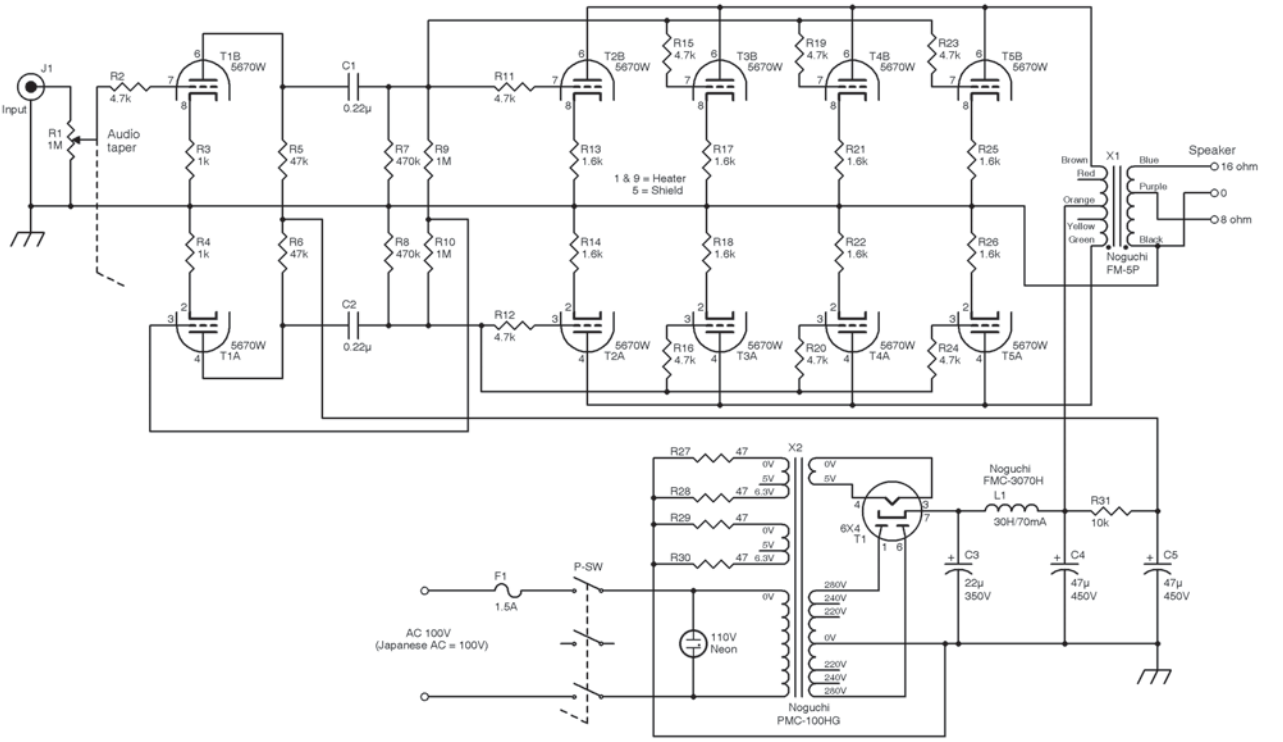


Figure 2: The schematic only shows one channel of the amplifier circuits because the second one mimics the illustrated one.

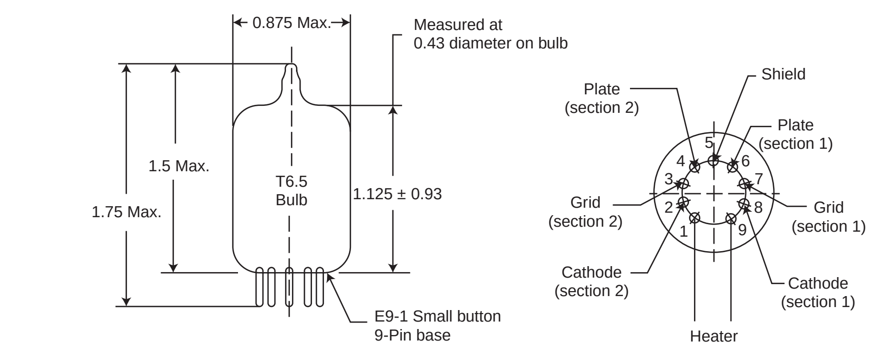
shows one channel of the amplifier circuits because both channels have the same configuration. The 5670W plate current is rated around 5 mA for each triode section. As a result, the total amount of plate current would be approximately 80 mA through 16 triode sections of eight 5670Ws. In April 2004, the Japanese audio magazine

Radio Technology published my article about a push-pull amplifier based on three parallel WE407As. Its output was a bit more than 2 W, so I estimated this project's amplifier would have a 3-W output. It is similar to a 2A3 SE amplifier's output.

Figure 3 shows the WE396A's typical push-pull operating condition. When using an 800-Ω cathode resistor for two triode sections and a 40-kΩ resistor as the load, the result is a 0.95-W output. In this project, I placed four 5670Ws in a parallel and used 10 kΩ as the load.

The first stage is also based on the 5670W. The phase splitter is the auto-balanced type. A 1.6-kΩ resistor provides cathode bias on the output tube's cathode. It is unbypassed, as this node is typically used to inject current negative feedback. I didn't apply the global negative feedback. The 4.7-kΩ resistor is a grid stopper to prevent spurious oscillation. There is a 1.6-kΩ cathode resistor for each triode section. This technique enables you to check each triode section's voltage.

As inputs, I used RCA connectors



Typical Operating Conditions—Class AB_1 Push-Pull Amplifier		
Plate voltage	200	300 V
Cathode resistor (cathodes tied together)	400	800 Ω
Peak A-F grid-to-grid voltage	9	20 V
Zero signal plate current per section	5	4.7 mA
Maximum signal plate current per section	5.6	6 mA
Load impendance, plate-to-plate	30,000	40,000 Ω
Signal power output	0.4	0.95 W
Total harmonic distortion	less than 5	10 %

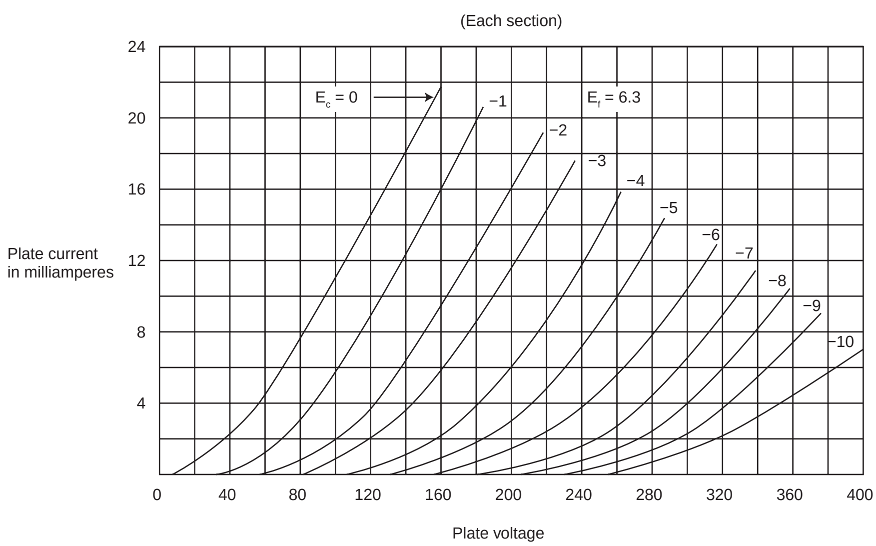


Figure 3: These specifications show a typical push-pull operating condition of the WE396A, which is similar to the 5670A.

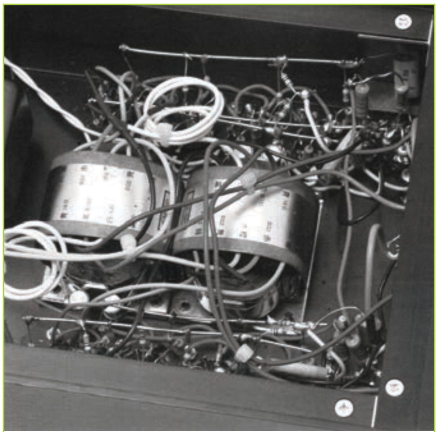


Photo 4: This is a close-up view of the amplifier's wiring.

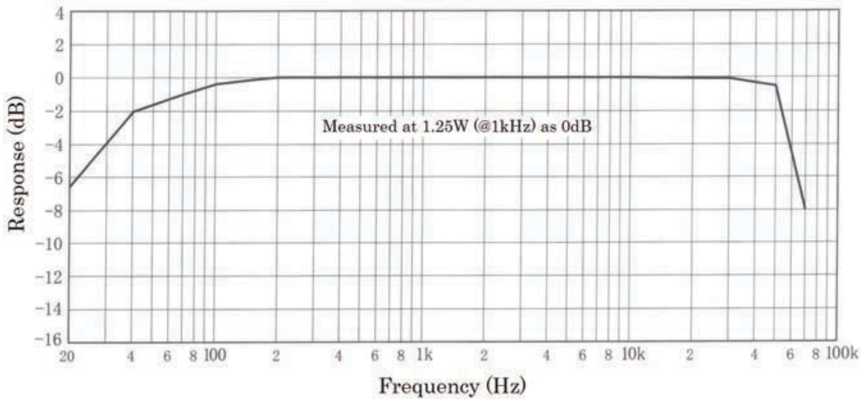


Figure 5: The amplifier's frequency response shows a respectable –1 db from 70 to 50 kHz. It features small output transformers, but the response is decent.

produced by Neutrik. I think the quality of the input connectors is critical to producing good sound. I used the 70-mm × 160-mm × 330-mm chassis because I needed a 70-mm depth to install output transformers and a power choke.

CONSTRUCTION

The selected construction is meant to make the amplifier as small as possible. It is fine as a low-output power amplifier. To accomplish this, I didn't use a lag board terminal around the tubes. Instead, I used 1-mm tin-plated wire to connect the signal to the 5670Ws' grids. I supported the wire with 4.7-kΩ grid resistors (see **Photo 4**). In **Figure 2**, you can see these two wires as two lines located above and below the 5670Ws. I also used the same method to install a grounding wire.

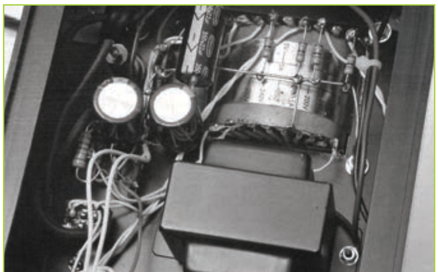


Photo 5: The power supply connections are shown.

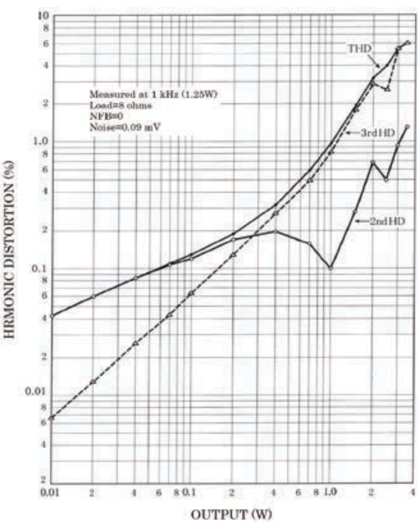


Figure 4: The harmonic distortion versus output shows a 5.4% THD at 3 W.

The high voltage is produced from 280-V taps of the power transformer, and it is rectified by a 4 × 6 tube. The Noguchi FMC-3070H power choke is rated at 30 hp and 70 mA. It also features a FINEMET core. **Photo 5** shows the power supply's connections.

PERFORMANCE

The total harmonic distortion (THD) measured 5.4% at 3 W (see **Figure 4**). The measured noise with no signal input is 0.09 mV. It is low noise due to applying the big power choke (e.g., 30 hp). The ripples of both phases in the high voltage use the push-pull configuration to cancel each other.

The amp manages a respectable –1 dB from 70 to 50 kHz (see **Figure 5**). It features small output transformers; however, the response result is good. When I received the 3-W maximum power, the input signal was 1 V (see **Figure 6**). If you are interested in applying the global negative feedback, you can try it because there is a margin.

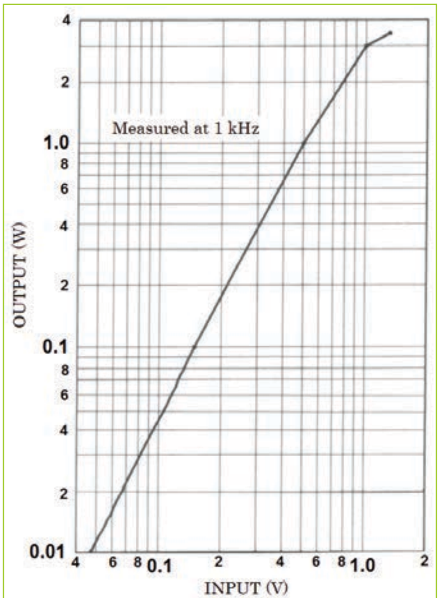


Figure 6: This figure shows output versus input. When the amplifier reached the 3-W maximum power, the input signal was 1 V.

SOUND EVALUATION

To evaluate the sound, I used a three-way speaker system based on the GIP4181 woofer, the WE555 midrange and the GIP597 Type 2 tweeter. The crossover is based on a transformer-type attenuator that also features the FINEMET core. Using this, I attenuated the response of the 555 and 597 by –2 dB. I made the crossover point of 4181 and 555 at 500 Hz/–6 dB. I applied a 4-µF capacitor to the 597 as a low-pass filter, which works at 2.5 kHz. I didn't apply any high-pass filter to the 555.

Starting the listening test, I was impressed with the richness of the low frequency. The sound flowed from the speakers, and I especially enjoyed classic and pop vocals. The sound was excellent and mature. In my opinion, the global negative feedback is unnecessary. Applying it could make the sound too tight. *aX*

Editor's note: This article first appeared in the Japanese magazine Radio Technology, *December 2011.*

 By Burkhard Kainka (Germany)

Valve Headphone Amplifier

Device uses vacuum tubes to increase the signal's amplitude

Heated debates rage over whether, and how, a valve amplifier sounds different from (or perhaps better than) a modern semiconductor amplifier. There certainly are reasons why a valve amplifier might sound different. First, there is the particular form of the characteristic curve (I_A plotted against U_G), whose gentle curve inevitably gives rise to increased distortion as the drive level is increased, especially when negative feedback is not employed. A modern semiconductor amplifier, on the other hand, almost always uses plenty of negative feedback to keep distortion to a minimum. However, the human ear itself is nonlinear at higher sound levels, so the valve's "natural" distortions can give the impression of a higher volume. Also, a transistor output stage suddenly produces extreme levels of distortion when overdriven, whereas a valve output stage clips more gently.

A second factor is the valve's extremely high internal impedance. The connected audio transducer is practically undamped, whereas in the case of an extremely low-impedance transistor output stage, all the self-resonances of a loudspeaker or headphones are strongly damped. This provides a flatter frequency response but simultaneously suppresses the particular character of the audio transducer. This is one of the reasons why many prefer the sound of older valve equipment. At the same time, it also creates a technical problem in the valve amplifiers' design, because a transformer is often required to match the audio transducer's low impedance.

The most important feature of this headphone amplifier is its safety, since it operates with a low anode voltage. The amplifier requires a 1 V_{PP} line-level input and provides plenty of output power (see **Photo 1**).

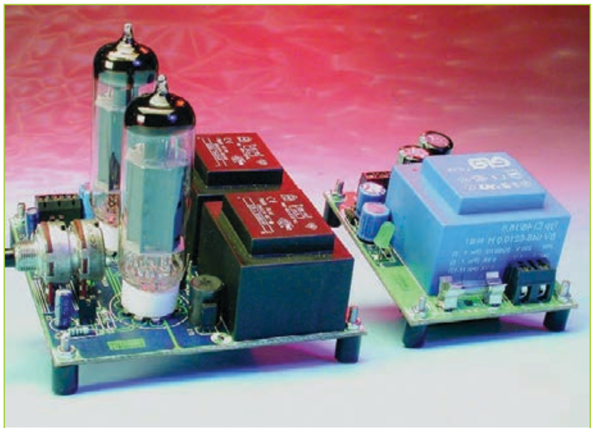


Photo 1: This valve headphone amplifier provides plenty of output power.

UNUSUAL USE FOR THE EL84

The EL84 (or its US equivalent, the 6BQ5), a 5-W power output valve usually found in radios, might seem a surprising choice here. Does it really make sense to operate this valve from just 40 V instead of the 250 V suggested in the datasheet? It does: The 40-V anode voltage is safe and entirely adequate for these purposes. There is a lower transconductance and a considerably lower anode current (of around 5 mA), but this does not do any harm to the valve. The anode power dissipation will be approximately 200 mW, so there should be more than enough output power to drive headphones.

The EL84/6BQ5 is also relatively inexpensive and readily available. It is still in production, as it is still used in many medium-power hi-fi amplifiers. Of course, an EL34 or an EL504 could also be used, although these devices are more expensive and harder to obtain, respectively.

The EL84/6BQ5 also makes power supply construction more straightforward. The valve requires a 6.3-V heater voltage and a 0.7-A heater current for a 4.5-W heater power. A 10-VA encapsulated mains transformer with two 6-V secondaries makes a suitable supply. In theory, the two heaters can be wired in series and a 12-V transformer can be used, but in practice, the heater voltages are not then equal. An arrangement like the power supply shown in **Figure 1** is better because each valve is supplied from its own transformer winding. The two windings are, nevertheless, in series, and it is straightforward to generate a DC supply at about 40 V for the anodes from this 12-VAC supply. Here, I use a tripler circuit.

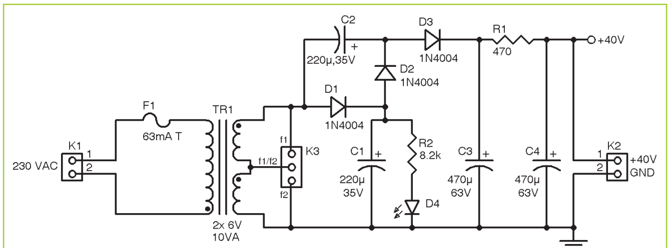


Figure 1: The valve headphone amplifier uses a simple power supply.

AMPS WITH & WITHOUT NEGATIVE FEEDBACK

The amplifier circuit in **Figure 2** shows a fairly typical Class A output stage, as used in loudspeaker amplifiers. The anode currents do not flow through the output transformers, since the magnetization caused by the DC component would lead to distortion. The audio frequency signal is taken via a volume control potentiometer to grid 1 (G1) of the valve. A 1-kΩ series resistor suppresses high-frequency oscillations. The screen grid (G2) is a supply potential, while the suppressor grid (G3) is connected to the cathode. The output signal at the anode is coupled to the audio transformer via an electrolytic capacitor (see **Photo 2**). Alternatively, high-impedance headphones may be directly connected to the coupling capacitors.

Compared to a triode, a pentode has a

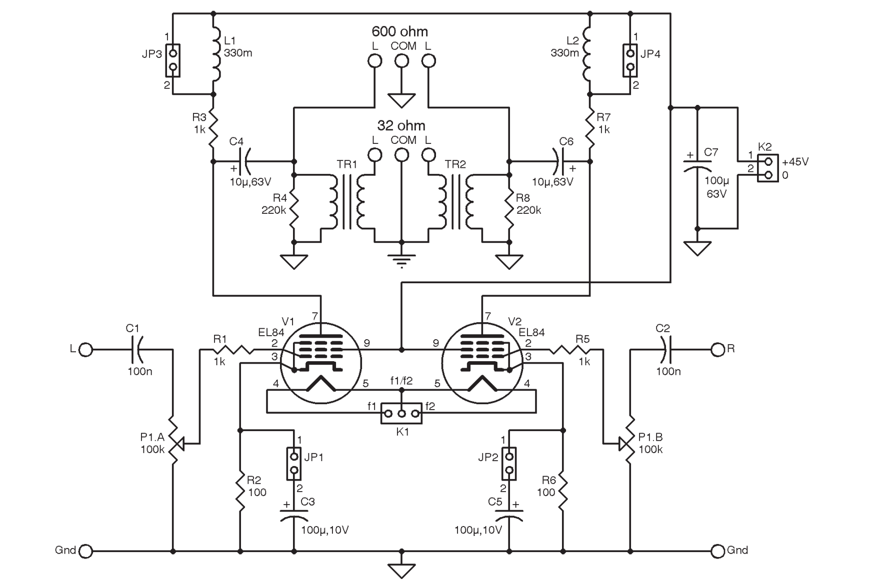


Figure 2: This circuit shows the amplifier with switchable negative feedback.

high internal impedance. This is extremely helpful in designing the amplifier and enables inexpensive mains transformers to be used at the output.

The voltage drop across the cathode resistor provides for a negative grid bias voltage relative to the cathode. The valve's operating point is set by this resistor. A 100-Ω value provides a 0.5-V grid voltage with a 5-mA anode current. At the same time, the cathode resistor provides a certain amount of negative feedback and a reduction in distortion in the valve without reducing the amplifier's internal impedance.

A particular feature of this circuit is that the negative feedback can be disabled by fitting jumpers JP1 and JP2, bringing the parallel 100-µF electrolytic capacitors into play. This affects the amplifier's sound and output power.

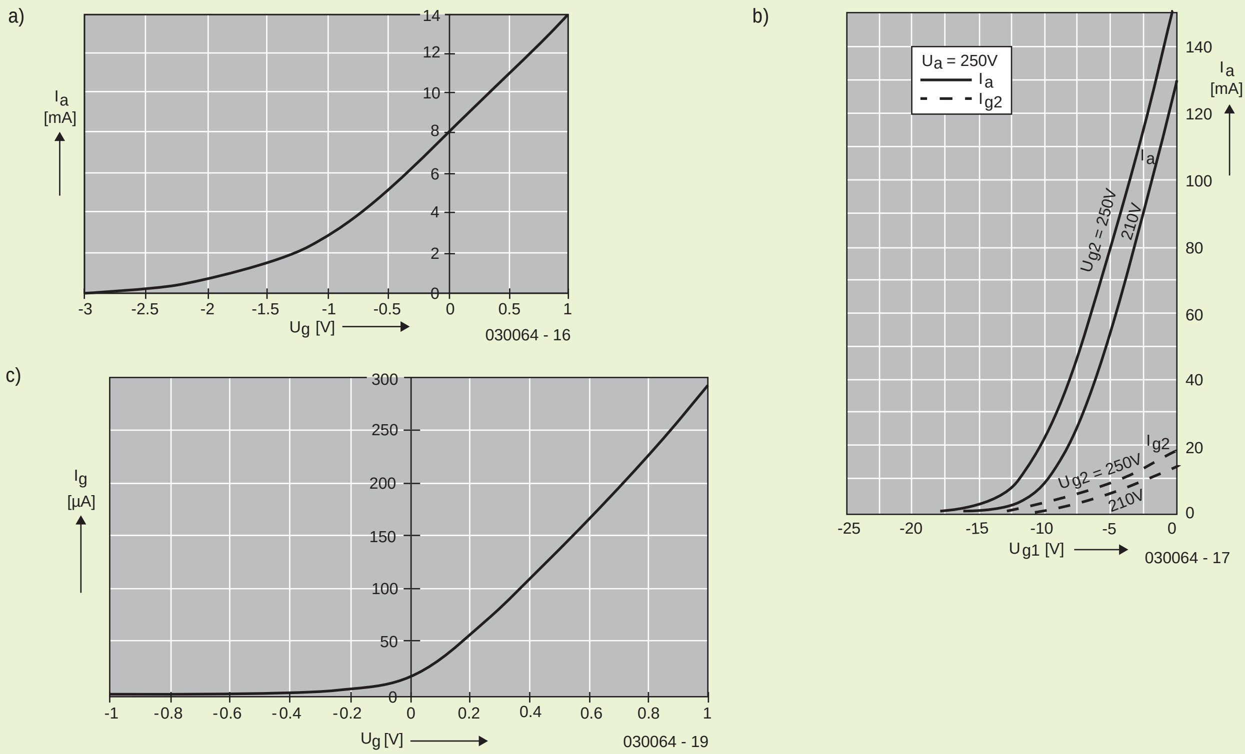
The two characteristic curves—at an anode voltage of 40 and at 250 V—exhibit a gentle curve and are similar to one another. It is here that the secret of "valve sound" lies. If no attempt is made to use negative feedback to straighten the characteristic curve, a certain distortion to the audio signal inevitably arises. These comprise harmonics and mixing products, chiefly odd multiples of the fundamental frequency, which are pleasant to the human ear. Since the ear does not work linearly at high volumes, a live concert at 100 dB sounds better than a recording. With a valve amplifier, the sound is also pleasant, and more "full," at lower volumes.

In the quiescent state, with U_G = −0.5 V, no grid current flows. When it is biased to 0 V, the peak grid current can be up to 20 µA, which flows through the


Photo 2: An electrolytic capacitor is used to couple the output signal at the anode to the audio transformer.


Photo 3: The output transformer is a key component to constructing a successful amplifier.

Characteristic Curves



The characteristic curve shows how the valve behaves at the reduced 40-V anode voltage **(a)**. Comparison with the curve from the datasheet shows similar behavior, although only at much higher currents **(b)**. This means the EL84 can be used in the same way it is used in a valve radio, albeit with lower output power. Also, when using a 40-V anode voltage, the grid bias voltage must be reduced. Comparing the two characteristic curves shows that its position shifts at lower anode voltages with lower anode currents and lower grid bias voltages. The optimal operating point lies at around U_G1 = –0.5 V and I_A = 5 mA. At full drive with a 1-V_{PP} audio frequency signal, the valve is then driven between –1 and 0 V, providing an anode current varying between 3 and 8 mA. When driven to around 0 V or slightly more, the grid current also becomes important. For this reason we also need to consider the grid current characteristic, which in turn is somewhat dependent on the anode voltage **(c)**. A higher anode voltage reduces the grid current, since free electrons are drawn toward the anode and fewer land on the grid.

100-kΩ volume-control potentiometer acting as a grid leak resistor. A conventional power amplifier with a higher anode voltage would use a 100-kΩ to 1-MΩ value. At lower anode voltages, this value is critical. Too high a grid leak resistance would result in an additional drop in grid voltage when a grid current flows. On the other hand, the amplifier's input impedance must not be allowed to go too low, or it may not be compatible with the line output of ordinary hi-fi equipment. A 100-kΩ potentiometer provides a suitable compromise.

THE SUBTLETIES OF TRANSFORMER SELECTION

Another key to constructing a successful amplifier is the output transformer selection (see **Photo 3**). A genuine audio transformer would have to be specially made for this application and would be very expensive. For that reason, I used a readily-available mains transformer. Excellent results can be achieved if you use the right type. A mains transformer can handle frequencies above 50 Hz if it has a suitable core size and the windings have the right inductance and DC resistance.

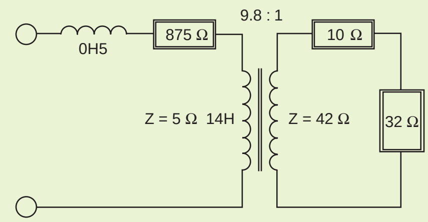
INDUCTANCE

The valve's output impedance is closely approximated by $R_A = U_A/I_A$. According to the EL84 datasheet, the valve should be operated at 250 V and 48 mA, implying an external impedance of around 5 kΩ. The datasheet actually recommends between 4.5 and 5.2 kΩ. At 40 V and 5 mA, 8 kΩ is obtained. If anything, the value chosen should be lower than this. Too low an external resistance leads to a lower AC component of anode voltage at the anode current's extremes. Since this means the anode voltage is less likely to reach zero, the result is a lower likelihood of distortion. Consider a transformer with a 12.8:1 (i.e., 230 V:18 V) turns ratio. The impedance ratio is to a first approximation 164:1 (i.e., 12.8^2:1). Thus a 32-Ω headphone impedance is transformed into an 5,240-Ω external impedance (see **Figure 3**). An 18-V mains transformer would, therefore, appear to be suitable. This argument is valid only when the transformer is directly in the anode circuit. In practice, the 1-kΩ anode resistors reduce the circuit's impedance. So, for optimal matching, a lower turns ratio is preferable. The additional coils L1 and L2 increase the impedance at higher frequencies, which together with the transformers used, provides an overall flat frequency response. When high-impedance headphones are used, these coils should be shorted by fitting jumpers JP3 and JP4.

Cutoff Frequencies

The transformer's equivalent circuit illustrates the connection of 32-Ω headphones **(a)**. The wire resistance of the secondary can be considered as 10 Ω in series with the load. Thus, there is a total of 42 Ω across the output. The actual 9.8:1 turns ratio provides an impedance ratio of 9.82:1 = 96:1. The primary has an impedance of 4,945 Ω, say 5 kΩ (i.e., 4,070 Ω + 875 Ω). This value fits well with the 8-kΩ theoretical value, which, in the interest of a pleasant sound, should be regarded as an upper limit. The low-frequency response is limited by the high-pass filter comprising this load resistance and the parallel inductance of 14 Hz **(b)**. The filter's –3-dB point can be computed as 56 Hz. In practice; however, a lower cutoff frequency of around 30 Hz is measured. Presumably, this difference can be attributed between theory and practice to the difficulties inherent in measuring the transformer's inductance. The upper cutoff frequency arises from the low-pass filter comprising the load resistance and the leakage inductance **(c)**. Using 4,945 Ω and 0.5 Hz, the cutoff frequency can be rather disappointingly calculated to be 1,574 Hz. A value in this range is measured if the transformer is connected to a low-impedance signal source. Fortunately, the valve's dynamic impedance is at least 10 times greater than the theoretical load resistance (here about 8 kΩ). Due to coils L1 and L2, the signal source has an impedance of more than 80 kΩ at the frequency range's higher end and the theoretically calculated upper cutoff frequency increases to more than 25 kHz. The leakage inductance also comes into play and, at higher signal levels, the valve more readily goes into clipping. In practice, this is often not a significant effect, since the distortion products lie outside the audio range.

a)



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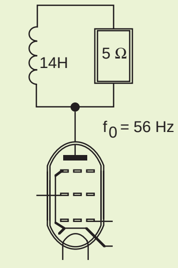
b)



Lower frequency limit
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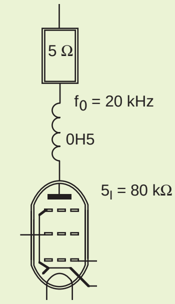
c)



Upper frequency limit
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CORE SIZE

In selecting a suitable core size for the transformer (which corresponds to rated power) the general principle is that a smaller transformer has a higher inductance and can operate at lower frequencies. Also, smaller transformers have thinner windings and greater resistance. So how large should the transformer be to guarantee the desired frequency response? The second consideration is the transformer's unavoidable leakage inductance. This can be thought of as being in series with the primary winding and forming a low-pass filter, which, in extreme circumstances, can impair high-frequency performance (see **Figure 4**).

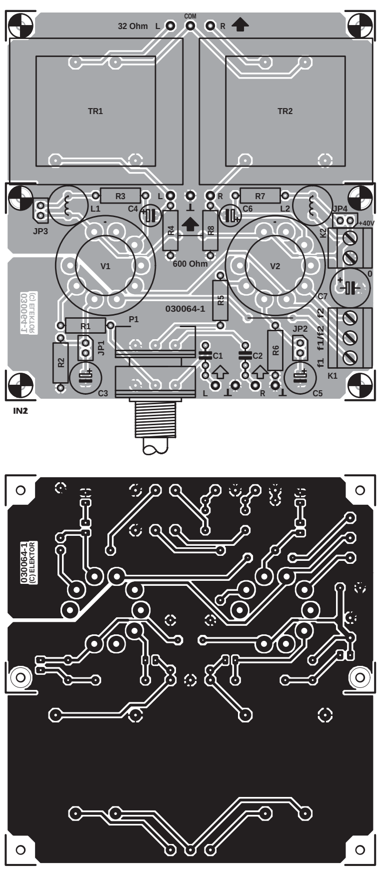


Figure 3: The printed circuit board layout is shown with a separate 32-Ω section.

DC RESISTANCE

The DC resistance of the windings and the exact turns ratio are important. Manufacturers often specify the open-circuit voltage ratio of small mains transformers. A transformer with a secondary voltage of 10 V at rated load might deliver 13 V with no load, providing a 30% load regulation. This must be taken into account when calculating the actual turns ratio. A good choice is a transformer with an EI42 core and rated at about 5 VA. The Gerth 4200 range includes a suitable one (available, for example, from Reichelt Elektronik, Germany, www.reichelt.de, order code 421.18-1). It is not too large, and, at about $3, it is also not too expensive. It will guarantee good sound quality with 32-Ω headphones.

HIGH OR LOW IMPEDANCE?

A frequency response from 30 Hz to 20 kHz into low-impedance headphones is good considering that it is achieved using an inexpensive mains

COMPONENTS LIST

Capacitors
- C1,C2 = 100 nF
- C3,C5 = 100 µF, 10-V radial
- C4,C6 = 10 µF, 63-V radial
- C7 = 100 µF, 63-V radial

Inductors
- L1,L2 = 330-mH choke (Toko 10RBH 239LY334K)

Miscellaneous
- JP1-JP4 = two-way pinheader with jumper
- K1 = three-way PCB terminal block, 5-mm lead pitch
- K = two-way PCB terminal block, 5-mm lead pitch
- TR1,TR2 = mains transformer 18 V/4.8 VA (Gerth # 421.18)
- PCBs, order code 030064-1 and 030064-2

Resistors
- R1,R3,R5,R7 = 1 kΩ
- R2,R6 = 100 Ω
- R4,R8 = 220 kΩ
- P1 = 100-kΩ stereo logarithmic potentiometer

Valves
- B1,B2 = EL84 or 6BQ5 with noval socket (18-mm diameter)

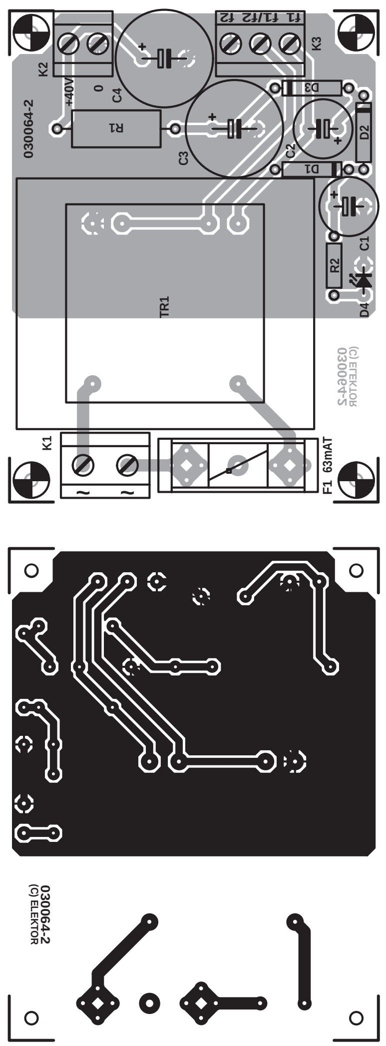
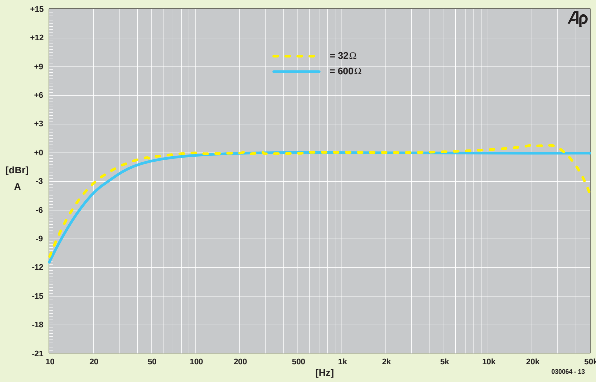


Figure 4: The printed circuit board shows the amplifier's power supply.

Frequency Response



The measurement shows the relative frequency responses of the amplifier with a 600-Ω load at the output (solid line) and with a 32-Ω load (dotted line). The curves were obtained with different anode voltages.

Input impedance	100 kΩ	
Sensitivity	600 Ω, 1 mW, JP1/JP2 open	620 mV (THD = 4.5%)
	600 Ω, 1 mW, JP1/JP2 closed	370 mV (THD = 7.4%)
	33 Ω, 1 mW, JP1/JP2 open	0.94 mV (THD = 7.5%)
	33 Ω, 1 mW, JP1/JP2 closed	0.59 V (THD = 9.9%)
Signal-to-noise ratio	600 Ω	>62 dB (B = 22 kHz linear)
(1 mW, JP1/JP2 open)		>88 dB(A)
	33 Ω	>65 dB (B = 22 kHz linear)
		>90 dB(A)
THD+N	600 Ω/1 mW	4.5%
(1 kHz, B = 80 kHz, JP1/JP2 open)	600 Ω/0.1 mW	1.1%
	33 Ω/1 mW	7.5%
	33 Ω/0.1 mW	3.5%
Bandwidth	23 Hz to >200 kHz (600 Ω)	
	20 Hz to 45 kHz (33 Ω)	

transformer. The alternative would be an expensive custom device using layered windings to reduce leakage inductance. The audio transformers used in professional valve output stages are large and expensive. An alternative to these specialized transformers is to experiment with types designed to be connected to a 600-Ω output. An interesting possibility would be to try ordinary 100-V audio line transformers (e.g., Conrad Electronics, www.conrad.com, order code 516104-77), which have multiple taps on the primary and secondary windings, enabling the matching to be adjusted.

Finding a suitable transformer for the output stage is worthwhile: 32-Ω headphones deliver a pleasant and warm sound, although the frequency response is not as linear as in a transformerless amplifier. None of these problems arise when using high-impedance headphones and capacitor coupling. Do not forget to compare the sound with and without the cathode capacitors. The choice here is between lower distortion and more "valve sound." A little negative feedback will do no harm when listening to classical music in all its transparent glory, but rock music definitely calls for a bit of valve-style distortion.

CONSTRUCTION

The printed circuit board includes a section providing 32-Ω matching that can be separated from the rest of the circuit (see **Figure 3**). There are no particular points to note about the construction: There are only two wire links (near R4 and R6). If the Toko chokes cannot be obtained, types from other manufacturers can be substituted. Since coils over 100 mH are rare and difficult to obtain, it is also possible to use smaller values in series. Alternatives include:

- Neosid BS75 (part number 0061243, 100 mH, 480 Ω, I_{MAX} = 5 mA, radial)
- Fastron XHBCC (part number XHBC-104J-01, 100 mH, 245 Ω, I_{SAT} = 60 mA, axial)
- Epcos B82144-A (part number B82144-A2107-J, 100 mH, 420 Ω, I_R = 20 mA, axial)

Of course, you can also use an RM8 former and an N67 core to wind the coils yourself.

If more output power is required, you can try using transformers with a higher secondary voltage. In this case, L1 and L2 would probably need to be adjusted. *aX*

Editor's note: This article first appeared in Elektor, *October 2003.*

By Gerd Lommersum (Germany)

The Apollon System

Designing the ultimate loudspeaker system

Every now and then a serious designer needs to leave the beaten path in pursuit of excellence, especially after considerable experience designing loudspeaker systems. Given that spirit, the Apollon represents an impressive and extravagant system. This freestanding unit shines with a remarkably low-frequency response, including a subwoofer that covers only the lowest octave and really packs a punch.

CHASSIS SELECTION

The selection of an appropriate speaker chassis for this project was done in no time (see **Photo 1**). As CEO and chief designer at ASE Loudspeaker Distribution Europe, I was able to simply select the Scan-Speak's best chassis namely, the Illuminator series chassis. Scan-Speak, a Danish high-end speaker manufacturer, developed new chassis designs following a visit to the US. The common key features include new and patented drivers with neodymium magnets, underhung voice coils and a so-called symmetric drive (SD) copper cap shield that, according to Scan-Speak, guarantees the lowest possible distortion during large speaker excursions.

For the midrange speaker chassis, Scan-Speak claims to produce the best audiophile transducers on the market. Besides its resolution, these drivers have strong ring-shaped neodymium

Photo 1: The Apollon is a sleek, freestanding speaker system with a low-frequency response.

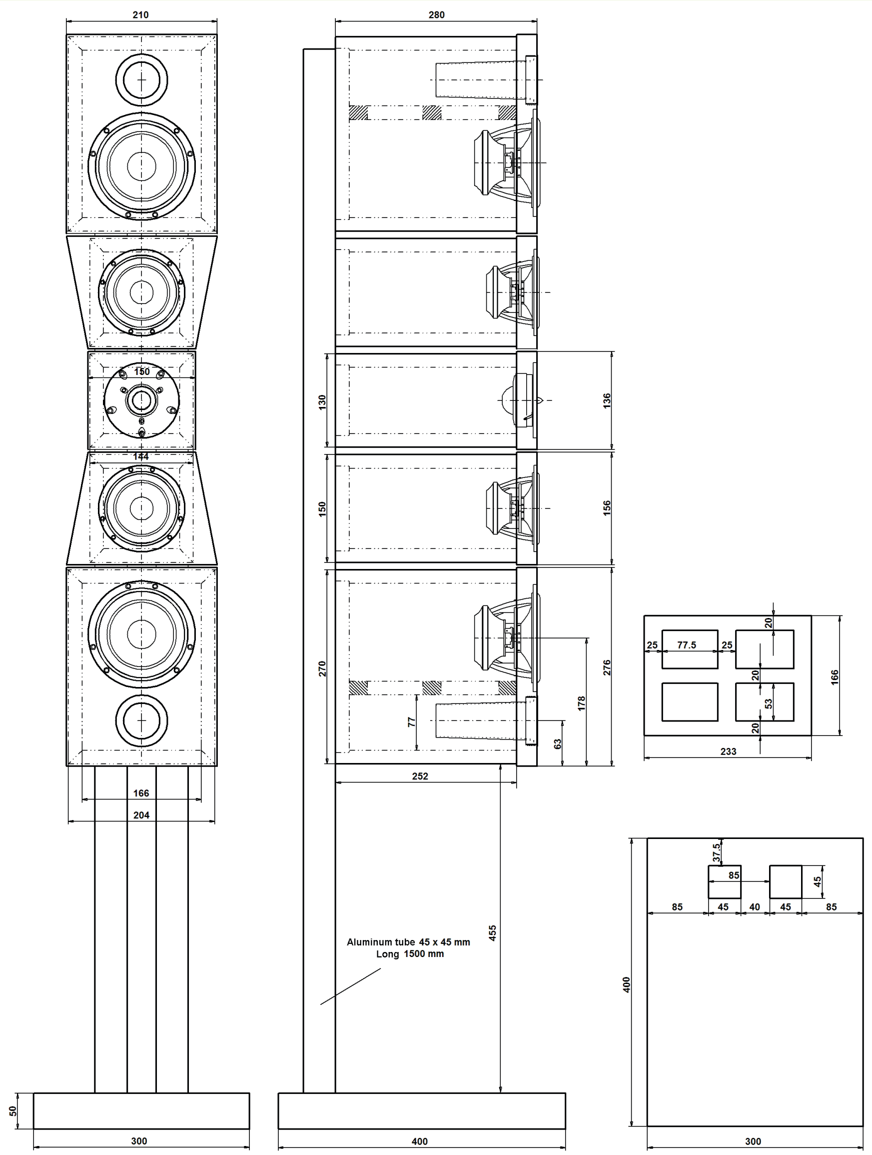


Figure 1: The loudspeaker design consists of five stacked enclosures, drawn in separate diagrams.

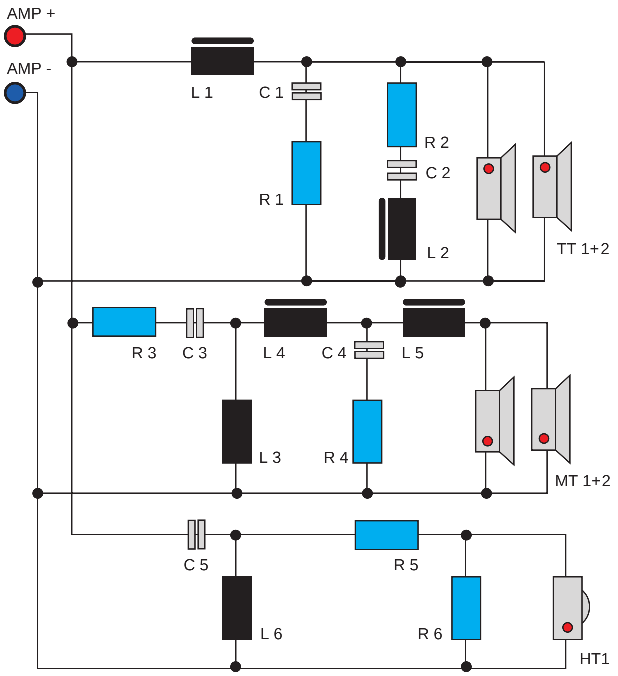


Figure 2: Three second-order filters cover all sections, only the low-pass filter feeding the midrange drivers MT1 + MT2 possesses a steeper falloff.

The Apollon System's Technical Data

- Three-way stand-alone loudspeaker box with bass-reflex tuning
- Volume (net): 9 + 9 ltr (bass)
- Volume (gross): 56 ltr
- Sine/music power rating: 120 W/ 200 W
- Nominal impedance: 4 Ω
- Crossover frequencies: 230 Hz/2,000 Hz

magnets and underhung voice coils ensuring constant precision over a wide range of membrane excursions. The entire motor system connects to the newly developed cone with a shaped top plate guiding the airflow around the motor, which prevents compression effects from occurring at the rear side of the membrane.

SPEAKER ENCLOSURES

Every chassis is mounted in its own rectangular medium-density fiberboard (MDF) enclosure, which close with a veneered front panel. The outer walls of the bass-reflex tuned enclosures are effectively stiffened out by additional wooden boards (see **Figure 1**).

The bottom plate connects to two vertical aluminum square bars, which are clamped to the enclosures' back plates. This arrangement allows for exact and convenient height adjustments. The tweeter position should coincide with the vertical position of the listener's ears. **Figure 1** shows this assembly.

PASSIVE CROSSOVER

In the bass section, the designer implemented a second-order low-pass filter via L1/C1 tamed by R1, which results in slightly less attenuation than the usual 12-dB/octave value (see **Figure 2**). The subsequent combination of R2/C2/L2 was designed to compensate a secondary impedance peak in the bass range. The transition to the midrange section performs another second-order low-pass filter with C3/L3. The tweeter range is cut off a bit steeper via L4/C4/L5, but it does not quite reach 18-dB/octave


Photo 2: Once complete, the enclosures are attached to the aluminum guidance bearings.

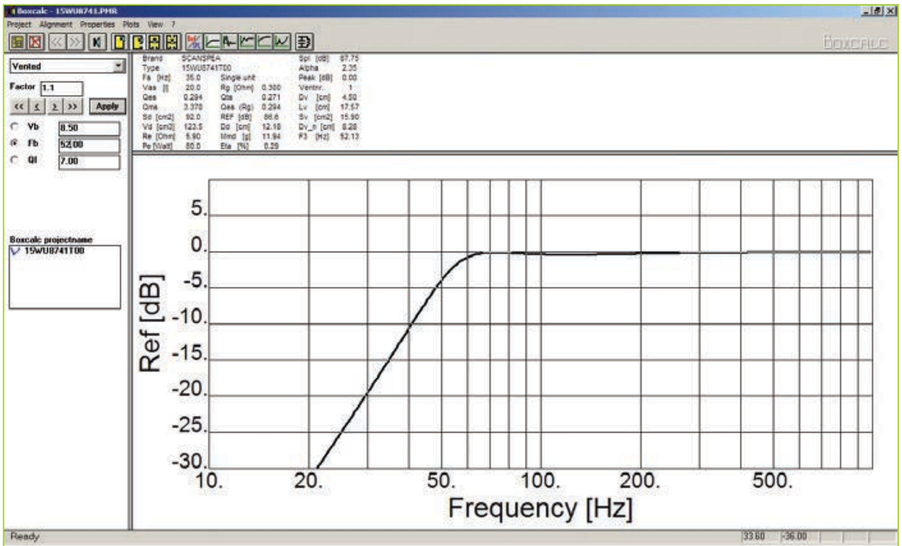


Photo 3: In a simulation, the woofer 15WU falls off at about 53 Hz.

attenuation due to R4. The woofers and midrange drivers reveal about the same efficiency, which means a single resistor, R3, is appropriate for matching these two sections (see **Photo 2**).

Capacitor C5 and coil L6 form a conventional high-pass filter for the tweeter. The voltage divider attenuates the signal by about –2 dB.

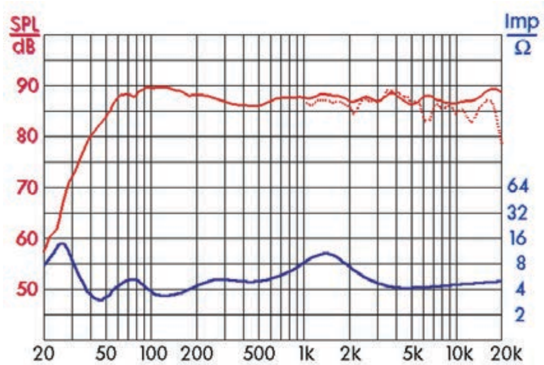


Figure 3: The results for the Apollon across frequency in action are not perfect, but fairly good.

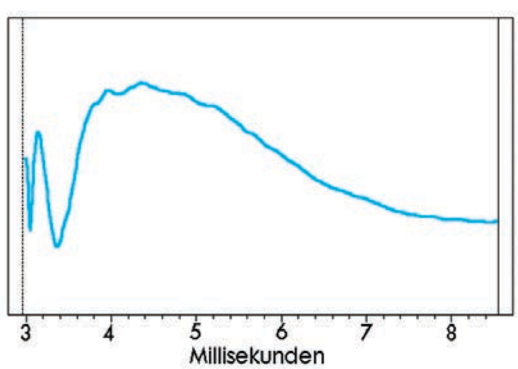


Figure 4: The midrange drivers and woofer show almost identical impulse responses.

THE MEASUREMENTS

The Apollon's measurements are rather inconspicuous. The weighted efficiency of 87.4 dB/2.83 V/1 m is upper average, and the low-frequency –3-dB point at 53 Hz is predictably in line with the results of a Boxcalc-Simulation (see **Photo 3**).

The amplitude spectrum shows a bump around 100 Hz, which will enhance the already pronounced bass response (see red trace, **Figure 3**). The graph also shows a flat response before a final 3-dB increase between 200 Hz and 15 kHz. The ripple in the mid- and high-frequency ranges is probably due to the individual enclosures' somewhat suboptimal design, which has a number of potentially significant edges and crevices.

The fact that the impedance curve (see blue trace, **Figure 3**) has been straightened out using all tricks of the trade is evident from the slightly dampened resonant bump peaking at about 75 Hz (see **Figure 4**). The 0.2-Ω dip at around 47 Hz is under the minimal impedance for 4-Ω speaker systems, but it is forgivable and flies under the radar (see **Figure 5**).

CROSSOVER PARTS & COMPONENTS

Capacitors

- C1 = 120-μF capacitor, electrolytic, bipolar, rough foil (100 μF + 22 μF)
- C2 = 200-μF capacitor, electrolytic, bipolar, rough foil (100 μF + 100 μF)
- C3 = 100-μF capacitor, MKT (or MKP), 100 VDC
- C4 = 12-μF capacitor, MKT, 100 VDC
- C5 = 10-μF capacitor, MKP

Inductors

- L1 = 3.9-mH coil, bobbin core, magnet wire Ø 0.95 mm, R ≈ 0.45 Ω
- L2 = 22.0-mH coil, pin core, magnet wire Ø 0.60 mm, R ≈ 4.2 Ω
- L2 = 3.3-mH coil, pin core, magnet wire Ø 0.60 mm, R ≈ 2.0 Ω
- L2 = 1.2-mH coil, bobbin core (HQ), R ≈ 0.3 Ω
- L2 = 0.39-mH coil, pin core, magnet wire Ø 0.71 mm
- L2 = 0.33-mH coil, air core, magnet wire Ø 0.71 mm

Miscellaneous components

- Tweeter driver: Scan-Speak D30004/660000
- Low mid-range driver: Scan-Speak 10MU8731T00
- Woofer: Scan-Speak 15WU8741T00
- System kit: approximately $1,987 (includes chassis, passive crossover, connection terminal, acoustic dampening material, and miscellaneous small parts)

Resistors

- R1 = 2.2 Ω, 10 W, ceramic
- R2 = 2.7 Ω, 10 W, ceramic (total resistance in RLC filter ≈ 6.8 Ω)
- R3 = 3.3 Ω, 10 W, ceramic (or metal film)
- R4 = 1 Ω, 5 W, ceramic
- R5 = 2.2 Ω, 5 W, ceramic (or metal film)
- R6 = 15 Ω, 5 W, ceramic

The following values for resistors R5 and R6 are recommended for the tweeter amplitude's attenuation: At −1 dB, R5 = 2.7 Ω and R6 = 12 Ω. At −2 dB, R5 = 3.3 Ω and R6 = 10 Ω.

Note: MKT and MKP are both types of plastic-film capacitors. MKT comes from the German *metallisierter kunststuff polyester*, which means metallized plastic polyester. MKP comes from the German *metallisierter kunststuff polyropylen* which means metallized plasctic polypropylene.

THE SOUND

I enthusiastically welcomed its first sounds when the Apollon system was initially tested. My first thought during the test was: This is in another league! The Apollon offers transparency, openness, a stage perfect in register, and no compression effects (even with complex and percussive sound material at almost ear-shattering volumes) delivered with effortless power far exceeding expectations.

The Apollon's performance satisfies all the demands required of a new reference speaker system. For more information, visit www.vifa.de. *aX*

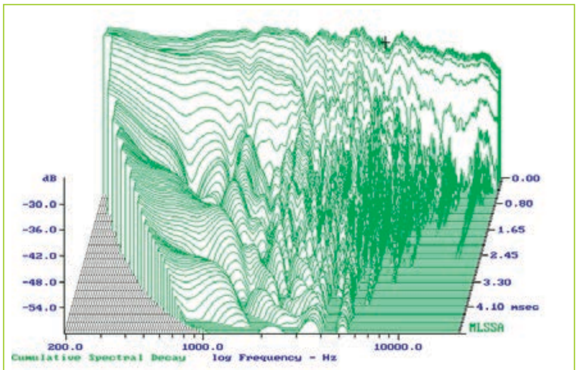


Figure 5: The Apollon system's waterfall diagram is shown here.

Editor's note: This article first appeared in Elektor Audio Special 3, *December 2009.*

 By Richard Honeycutt (United States)

Troubleshooting Power Supplies for Hollow-State Equipment

Logical, step-by-step method reveals most malfunctions

Enemies of electronic equipment include heat, lightning-induced voltage peaks, and power surges. The power supply in any piece of electronic gear is on the front lines in facing these enemies. Thus, the power supply is the most likely subsystem to fail.

Power-supply failures in hollow-state audio equipment include blown fuses, low or distorted audio, hum, or a complete failure to operate. The presenting symptom is the best place to begin diagnosing a power-supply problem.

BLOWN FUSES

The purpose of a fuse is to prevent overcurrents that can cause further damage or even fires. Thus, almost all blown fuses result from a condition that causes some sort of overcurrent. In hollow-state equipment, such conditions include shorted output tubes, shorted rectifiers, shorted filter capacitors, and shorted power transformers. “Shorted” means that the resistance in a device is too low, causing it to draw excess current. A short circuit can occur between elements of a tube, from anode to cathode of a solid-state rectifier, between the plates of a capacitor, or between adjacent windings in a power transformer. (Please don’t refer to such a fault as a “shortage,” as did a former customer during my repair-technician days. This customer, bringing in a piece of equipment for repair, offered the opinion that “it must be some kind of shortage.” I never did find out what he thought there was a shortage of—electrons, I suppose.)

For safety’s sake, ensure the equipment’s power plug is unplugged whenever you’re messing around in the innards. I have been zapped more than once by circuits whose power switches were turned off.

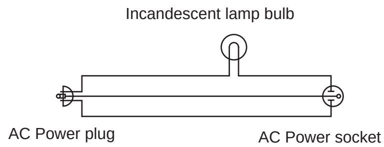


Figure 1: This incandescent bulb test fixture can save fuses when you’re testing power supplies with short circuits.

Troubleshooting a blown fuse should begin with a visual inspection of the whole circuit. You should look for wires whose insulation has been skinned or pinched, enabling the conductor to contact something it shouldn’t. Also, keep an eye open for crispy critters. Shorted solid-state rectifiers often appear charred or cracked, and the circuit board (if there is one) may be discolored near the rectifier. Look for bulging electrolytic filter capacitors, especially in older equipment. Some types of output tubes are prone to shorting internally and, in such cases, the output-tube sockets may be discolored. If you suspect bad output tubes, use a good tube tester to test them, tapping on each tube as it is being tested. You may see the meter needle wiggle if the tube’s supporting structures have weakened. If you encounter suspect components, replace them and see if the problem has been corrected.

If, after looking, you haven’t found any obvious problems, it’s a good idea to replace the fuse and try the circuit again. Especially in portable equipment, vibration can open fuses. Open fuses are not necessarily visible through the fuse glass, as the break may be near the end of the fusible wire.

Two stories may prove interesting. The first dates from a 1950s Navy training class. The students met outside of class and agreed on a challenge for the instructor. If they could cause a failure in one of the pieces of training equipment that the instructor could not fix within 10 min., he would buy the entire class a steak dinner. If he repaired the equipment within 10 min., they would have to buy him and his wife a steak dinner. The instructor agreed. The class knew the instructor’s experience would lead him to the solution of any complex problem, so they decided on something simple—a blown fuse. They then carefully blew all the spare fuses in the parts box. Since these were ceramic-cased fuses, their damage presented no visible evidence. When the test began, the instructor flipped the power switch and nothing happened. Then he replaced a fuse. Still nothing. Then he replaced the new fuse with another fuse and, of course, had the same non-results. Next, he used an ohmmeter to measure all the remaining fuses. He and his wife enjoyed the steak dinner!

The second story makes the same point in a slightly different way. When I was in college, a friend asked me to check his stereo amplifier, which was not working. I found nothing obvious on visual inspection, and all three fuses (one power fuse and two fuses in the speaker output lines) looked good. I did not have a schematic diagram, but the voltages feeding the amplifier circuit looked reasonable when I measured them. I traced the signal from input to output, one stage at a time. To my surprise, the signal waveform and amplitude looked fine—right up to the output from the circuit board. But there was still nearly nothing at the output terminals. I finally removed the output fuses and measured them. Although they looked good, each one measured more than 10 kΩ. The amplifier had been operated at a high enough level that the fusible wire inside had partially evaporated, leaving only an extremely thin, very high-resistance strand. But it looked good! The moral, of course, is to test fuses whenever you find anomalous things happening.

Chasing the causes of blown fuses can prove expensive if you sacrifice a fuse every time you think you have fixed the problem, but haven't. To avoid this, make and use a test fixture that connects an incandescent light bulb in series with the equipment being tested (see **Figure 1**). Choose a bulb with wattage that is two to three times the power normally drawn by the circuit under test (see **Photo 1**). When the light bulb's filament is cold, it has a low resistance. If the circuit under test is not drawing too much current, it will behave more or less normally. But if it is drawing too much current, that current will heat the light bulb's filament, causing its resistance to rise dramatically. This can limit the current that can be drawn and saving the fuse. An added advantage is that the brightly illuminating bulb indicates that you still have something drawing too much current. And, no, so-called "green-friendly" light bulbs will not work for this purpose. You must use an incandescent bulb.

Photo 1: The test fixture connects an incandescent light bulb in series with the equipment being tested. If the bulb lights, something is drawing too much current.

Once you have established that the fuse itself is not the problem, your next job is to find out what is drawing too much current. If the circuit has a solid-state rectifier, disconnect one end and test the rectifier using an ohmmeter that can test solid-state diodes. (Some solid-state meters only apply a few hundred millivolts when measuring resistance, and a solid-state diode typically requires 0.6 V to turn on.) If you get conduction both ways through the rectifier, it is destroyed and must be replaced by a unit of equivalent or higher voltage and current ratings. Shorted solid-state rectifiers can be caused by power-line surges or by shorted filter capacitors. Your light bulb test fixture will protect the replacement rectifier from being shorted in the event the filter capacitor is shorted.

Hollow-state rectifiers can just be unplugged to see if they are destroyed. If unplugging the rectifier prevents the overcurrent, you know you have a bad rectifier or filter capacitor, or that the circuit being powered is drawing too much current. If a new rectifier tube does not fix the problem, you have to keep looking.

To determine whether the circuit being powered is drawing too much current, unplug the output tubes if it is a power amplifier, or all the tubes if it is any other kind of circuit. A tube that is drawing too much current for a significant time period may "hot-plate"—the plates will glow red. Alternately, if some atmospheric gas has leaked into the tube, ionization can cause a bluish glow near the internal elements. The glow caused by ionization should not be mistaken for the glass envelope's normal fluorescence caused by the glass being struck by stray electrons. Careful observation will reveal whether the glow is coming from the glass or from inside the tube. "Gassy" tubes can draw excess current and will usually generate noise ("static") in the output signal.

If unplugging the output tubes keeps your test fixture's incandescent bulb from illuminating, the problem may not be in the power supply and, therefore, not within the scope of this month's article. However, check the output tubes' bias voltage. Sometimes bias filter capacitors short, enabling the output tubes to draw as much current as they can get. The bias voltage can be measured with the output tubes removed. If the voltage is too low, replace the bias filter capacitor and the bias rectifier. If one is bad, both are probably bad, and replacing them is cheap insurance.

If the circuit still draws too much current even with the output tubes removed, the problem could be a shorted filter capacitor. Leaving the output tubes unplugged, disconnect the lead from the rectifier to the filter capacitor and turn the circuit on. If the incandescent bulb does not illuminate brightly, the filter capacitor is shorted and must be replaced. Ohmmeter tests don't always reveal shorted filter caps, so the full-voltage test described here is more reliable. If the bulb illuminates brightly even with the filter cap disconnected, then you confirmed that the problem is what you hoped it wouldn't be—a shorted power transformer. (Shorted power transformers often reveal themselves by a characteristic stench often described as "metallic," "burnt varnish," or just "yuck!") **Figure 2** shows places where short circuits may lurk in a power supply.

LOW OR DISTORTED AUDIO

If the audio output is low in level or is distorted, the fault may be low power-supply voltage. This can be caused by a bad hollow-state rectifier or a leaky filter capacitor. Using a tube tester or replacing the rectifier tube with a known good one will identify or exonerate the rectifier tube as the problem. The best way to test for a leaky filter capacitor is to replace it with a known good one. If the original cap is a twist-prong type, you can desolder the leads and use clip leads to try connecting a new one. Thus, you avoid the substantial effort of unnecessarily replacing a twist-prong cap in the event the original one is not defective. Always remember to discharge these capacitors after turning off the power and before handling them, to avoid unpleasant surprises and outbursts of non-family-friendly language.

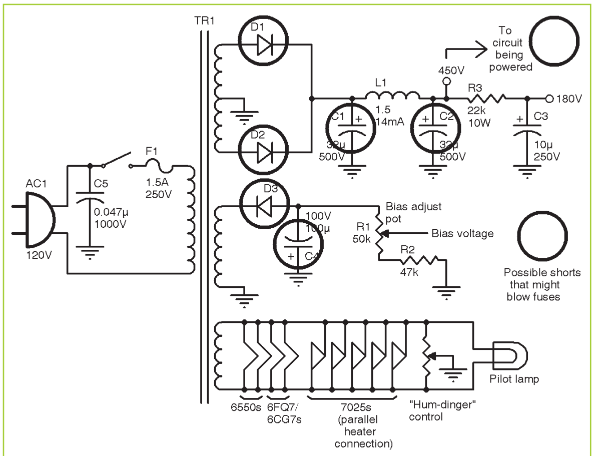


Figure 2: The circles in this figure highlight the most likely locations of short circuits that can blow fuses.

One other possible cause of low "low B+" power-supply voltage cause is a voltage-dropping resistor that has changed value. To test for this, power the circuit down, use a screwdriver to short across each filter capacitor, then disconnect one lead of the dropping resistor and use an ohmmeter to measure the resistance. If it is not within 10% of the rated value, replace it. After replacing a dropping resistor, if you find that the low B+ voltage is still low, the filter capacitor is probably leaky. Although resistors can change value with age, overcurrents can also be the cause, so replacing the low B+ filter capacitor is a good idea after you find a dropping resistor with too high a resistance.

HUM IN AUDIO CIRCUITS

There are many possible causes of hum in audio circuits. But if the circuit previously worked well, then began to hum, the likely possibilities are reduced to three: a bad (open or high-equivalent-series-resistance) filter capacitor; excessive current being drawn from the power supply, though not enough to blow the fuse; or a bad amplifier tube. Less likely, though possible, is a ground connection that has somehow opened.

The easiest way to check a filter capacitor to see whether it is causing hum is to use chip leads to temporarily connect a new one across the original unit. It is not necessary to disconnect the old capacitor for this test. If jumping a new capacitor across the old one kills the hum, remove and replace the old capacitor. (Aside from neatness considerations, if the old capacitor is left in place, it may eventually develop a short, blowing a fuse and forcing you to reread the first part of this article.)

Excessive current can cause hum because a capacitor filter has more ripple in its output when more current is drawn. Such excessive current can be caused by a low bias voltage on the output tubes (possibly resulting from a leaky bias filter capacitor) or by a bad output tube. You can measure the bias voltage and determine if it is high enough. Output tubes can be tested by a tube tester or by replacement with good units.

Internal support structures in tubes can weaken over time due to temperature cycling and vibration. The resulting shift in the positions of the elements in the tube can cause hum. This type of fault may not always show on a tube tester, so replacement with a good tube is the best test.

COMPLETE FAILURE TO OPERATE

If your equipment is dead in the water with no pilot lights or other signs of life, and the fuse is not blown, you have an open circuit in the power supply. My 1924 Atwater-Kent radio behaved this way when I first tried to power it up. The radio had spent 20 years in my grandfather's attic and the problem was a dead power switch. You can check the power switch either by unplugging the unit from the AC mains and using an ohmmeter to measure across the switch, or by measuring for AC voltage across the switch. Since the switch should have almost no resistance, there should be no voltage drop across it when it is in the ON position. If you measure a significant voltage, the switch should be replaced with one of equal or greater voltage and current ratings.

If the switch is good, you may have an open rectifier. Check a hollow-state rectifier by substituting a good one. You can test a solid-state rectifier by using an ohmmeter with test voltage over 0.6 V. The rectifier should conduct in only one direction. If the rectifier is open, replace the rectifier and use the light bulb test fixture when powering up the unit. One cause of open rectifiers is overcurrents due to shorted filter capacitors. If the bulb does not brightly illuminate, the filter capacitor is not shorted and the rectifier may have been opened by a power or lightning-induced voltage surge.

In low-current equipment, power transformer primary windings sometimes open because of line-voltage surges. Occasionally, secondary windings open due to overcurrents in the circuit to which power is being supplied, or due to shorted filter capacitors. Transformer windings may be tested with an ohmmeter, once the unit under test is unplugged.

With the information in this article, you are now prepared to tackle the vast majority of power-supply problems in hollow-state circuits. Next month, I'll discuss some popular amplifier tubes. *aX*

By Vance Dickason (United States)

A Coax Driver from B&C Speakers

The new series uses ferrite motors for both the compression driver and the woofer

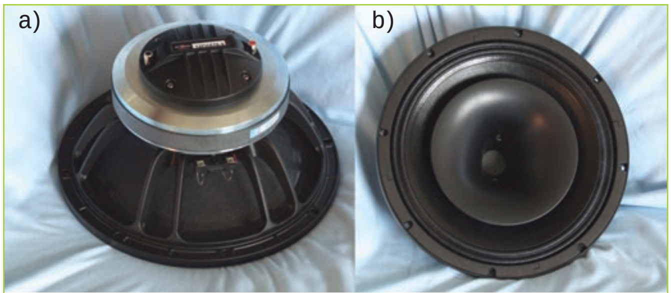


Photo 1: The bottom view (a) and top view (b) of B&C Speakers's 12FHX76 coaxial driver

For this month's driver review, I received the 12FHX76, another driver in B&C Speakers's new line of pro sound coaxial speakers.

B&C Speakers recently released a new series of four pro sound coaxial drivers, the 5.25" 5FCX44, the 6.5" 6FHX51, the 12" 12FHX76, and the 15" 15FHX76. The 5FCX44 was featured in the December 2012 issue of *Voice Coil*. This month, I got a chance to test the 12FHX76 (see **Photo 1**).

The 12FHX76 pro sound 12" coaxial driver keeps with the current ferrite motor trend, and uses ferrite for both the compression driver and the woofer. In terms of features, the 12FHX76 woofer is built on a 12-spoke (actually consisting of six double spokes) cast aluminum frame with eight mounting holes. For cooling, there are 12 vents (2 mm × 15 mm) between the frame's back and the motor's front plate. They open into the plate area and provide an air path across the front plate and voice coil. Attached to the frame is the woofer's ferrite motor structure with the compression driver attached to the woofer's back plate, firing into what would normally be a pole vent. The woofer motor utilizes a 21-mm × 190-mm ceramic magnet sandwiched between a polished and shaped front plate and a polished and shaped back plate. A fairly large, modified exponential flared (conical) aluminum horn attached to the pole piece's top completes the compression driver. The compression driver's visible motor parts include the shaped rear plate with eight heatsink fins.

The 12FHX76 woofer cone assembly includes a curvilinear front-coated paper cone suspended by a coated-cloth M-shaped surround and a 5.25" diameter flat-cloth spider. A porous metal screen is used to cover the compression driver's throat area at the horn's base to keep extraneous material out of the compression driver. Coupling the cone to the driver motor is a 76-mm (3") diameter voice coil wound with copper wire on a non-conducting former terminated to a solderable terminal block. For the high-frequency compression driver, B&C incorporates a titanium diaphragm coupled to a 75-mm (1") voice coil wound with aluminum wire.

Testing commenced with this coax driver's woofer half using the LinearX LMS and VIBox to produce both voltage and admittance (current) curves. The driver was clamped

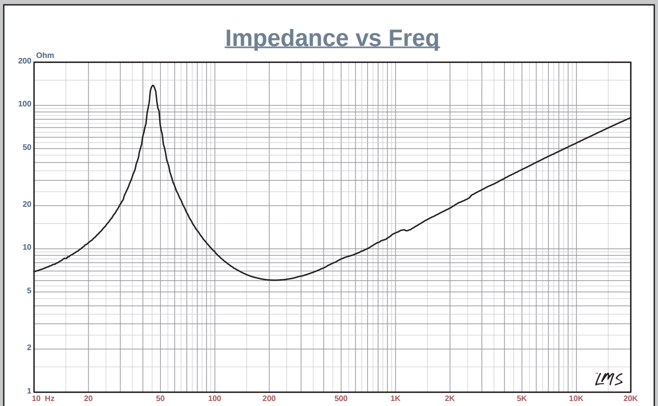


Figure 1: B&C 12FHX76 woofer free-air 1-V impedance plot

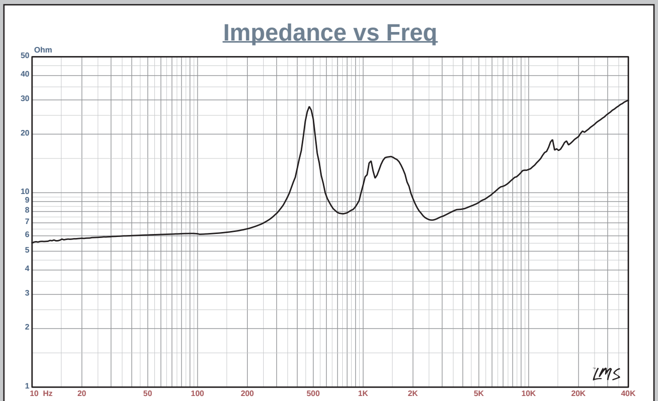


Figure 2: B&C 12FHX76 compression driver free-air impedance plot

	TSL Model		LTD Model		Factory
	Sample 1	Sample 2	Sample 1	Sample 2	
F_S	46.4 Hz	45.5 Hz	44.6 Hz	44.5 Hz	48 Hz
R_{EVC}	5.26	5.26	5.26	5.26	5.2
Sd	0.0535	0.0535	0.0535	0.0535	0.0522
Q_{MS}	9.97	8.97	9.42	8.12	5.4
Q_{ES}	0.35	0.33	0.34	0.32	0.36
Q_{TS}	0.33	0.32	0.32	0.31	0.33
V_{AS}	105.9 ltr	105.5 ltr	110.3 ltr	111.2 ltr	88 ltr
SPL 2.83 V	96.4 dB	96.6 dB	96.5 dB	96.7 dB	98 dB (1 W/1 m)
X_{MAX}	6.5 mm	6.5 mm	6.5 mm	6.5 mm	6.5 mm

Table 1: B&C 12FHX76 coaxial driver's test analysis

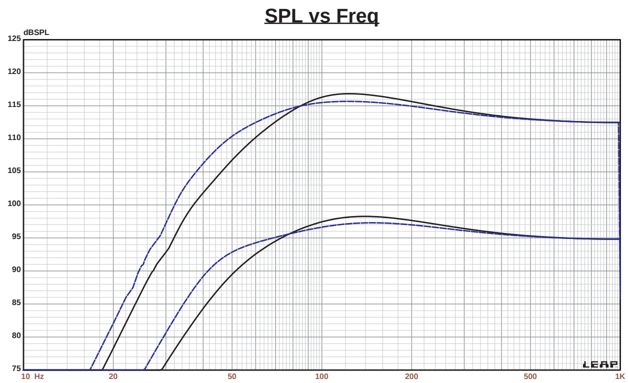


Figure 3: B&C 12FHX76 computer box simulations (black solid = vented 1 at 2.83 V; blue dash = vented 2 at 2.83 V; black solid = vented 1 at 20 V; and blue dash = vented 2 at 20 V)

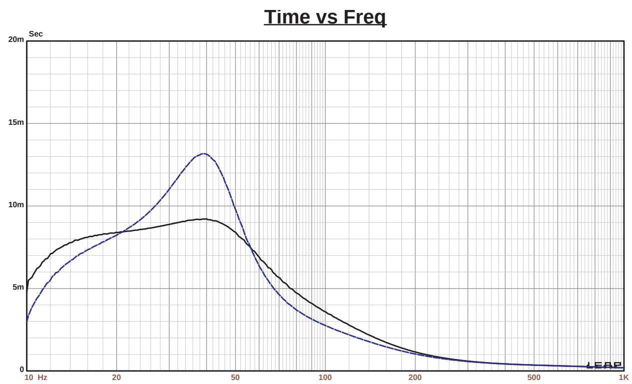


Figure 4: Group delay curves for the 2.83-V curves in Figure 3

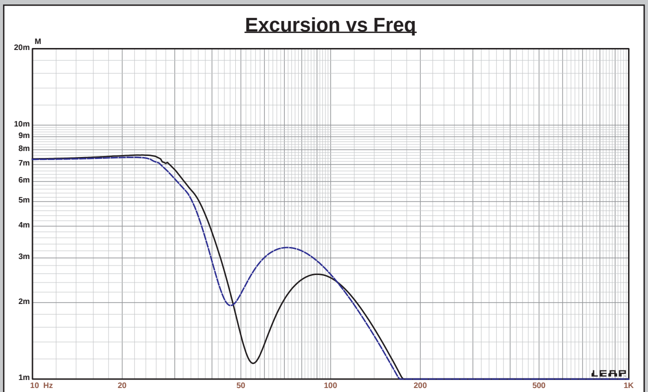


Figure 5: Cone excursion curves for the 20-V curves in Figure 3

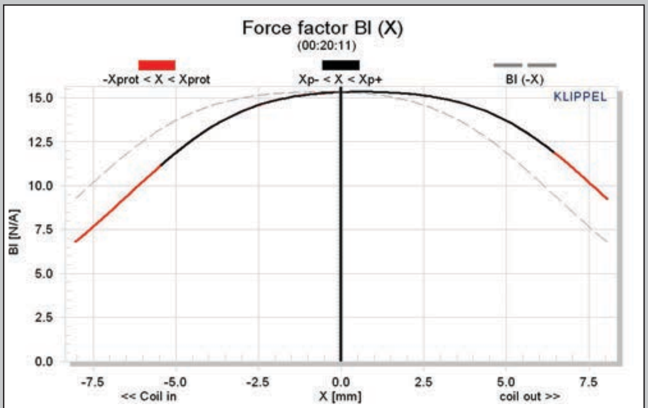


Figure 6: Klippel analyzer Bl (X) curve for the B&C 12FHX76

to a rigid test fixture in free air at 1, 3, 6, 10, 20, and 30 V. Note that the LMS oscillator is turned on for a progressively increasing time period between sweeps to keep the driver heated as close to the third-thermal time constant as possible (i.e., from 10 to 30 s between sweeps, depending on the voltage level). Following the established Test Bench test protocol, I no longer use a single-added mass measurement. Instead, I use the actual measured cone assembly weight provided by B&C. The 12FHX76 woofer motor stayed fairly linear throughout the test sequence and none of the curves were discarded.

Next, I post-processed the 12 550-point stepped sine wave sweeps for each sample and divided the voltage curves by the current curves to derive impedance curves, phase calculated, and along with the accompanying voltage curves, imported them to the LEAP 5 Enclosure Shop software. Because most TS data provided by OEM manufacturers is produced using either a standard model or the LEAP 4 TSL model, I additionally created a LEAP 4 TSL model using the 1-V free-air curves. The complete data set, the multiple voltage impedance curves for the LTD model, and the 1-V impedance curves for the TSL model were selected in LEAP 5's transducer derivation menu and the parameters created for the computer box simulations. **Figure 1** shows the woofer's 1-V free-air impedance curve. **Figure 2** shows the compression driver's impedance curve. **Table 1** compares the LEAP 5 LTD and TSL data and factory parameters for both B&C 12FHX76 samples.

The 12FHX76's parameter measurement results were reasonably close to the factory data except for some deviation in the V_{AS}. Given that, I used the LEAP LTD parameters for Sample 1 to set up two computer enclosure simulations. This included two vented alignments, a QB3 alignment, and an extended bass shelf (EBS). This resulted in a 1.4-ft^3 box with 15% fiberglass fill material tuned to 54 Hz for the QB3, and a 2.4-ft^3 box for EBS-vented alignment tuned to 45 Hz, also with 15% fiberglass fill material.

Figure 3 shows the results for the 12FHX76 woofer in the two vented boxes at 2.83 V and at a voltage level high enough to increase cone excursion to X_{MAX} + 15% (7.5 mm for the 12FHX76). This produced a F3 frequency of 74 Hz (–6 dB = 59 Hz) for the 1.4-ft^3 box tuned to 54 Hz and –3 dB = 60 Hz (–6 dB = 45 Hz) for the 2.4-ft^3 box EBS-vented simulation tuned to 45 Hz. Increasing the voltage input to the simulations until the maximum linear cone excursion (X_{MAX} + 15%) resulted in 117 dB at 25 V for the QB3 enclosure simulation and 115.8 dB at the same 25-V input. See **Figure 4** and **Figure 5** for the 2.83-V group delay curves and the 25-V excursion curves.

Klippel analysis for the B&C 12FHX76 (Klippel GmbH provided the analyzer and Pat Turnmire, Red Rock Acoustics performed the analysis), produced the Bl(X), K_{MS}(X) and Bl and K_{MS} symmetry range plots shown in **Figures 6–9**. (If you don't own a Klippel analyzer and would like to have analysis done on a particular driver project, Red Rock Acoustics can provide Klippel analysis of almost any driver. For contact information, visit www.redrockacoustics.com.)

The 12FHX76 woofer's Bl(X) curve is moderately broad and mostly symmetrical with some offset (see **Figure 6**). The Bl symmetry plot has a small 0.63-mm

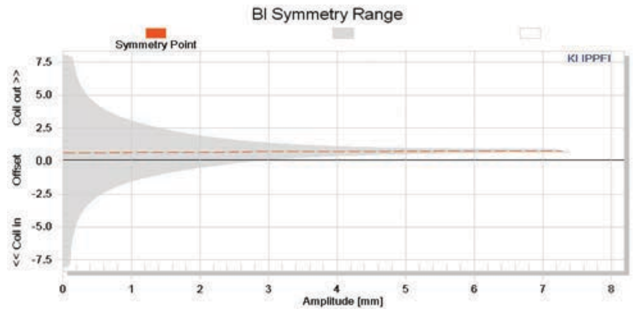


Figure 7: Klippel analyzer Bl summetry range curve for the B&C 12FHX76

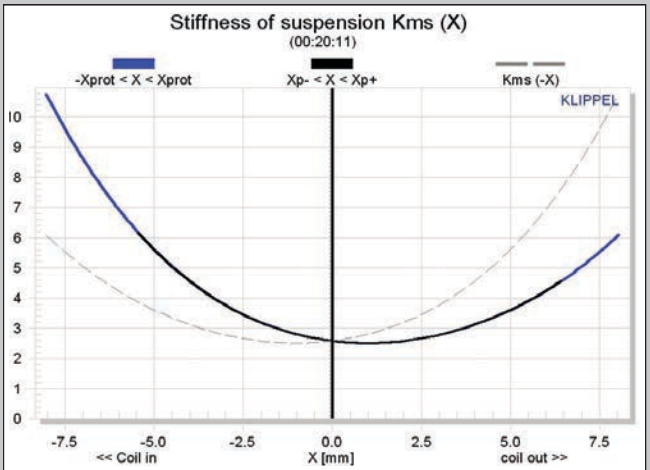


Figure 8: Klippel analyzer mechanical stiffness of suspension K_{MS} (X) curve for the B&C 12FHX76

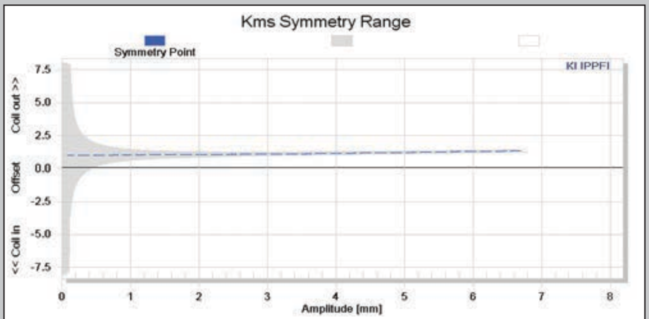


Figure 9: Klippel analyzer K_{MS} symmetry range curve for the B&C 12FHX76

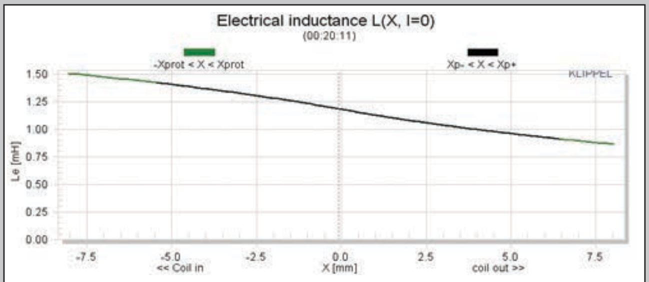


Figure 10: Klippel analyzer L(X) curve for the B&C 12FHX76

forward (coil-out) at the rest position and only increases to 0.86-mm at the driver's physical X_{MAX}, suggesting that this driver is just slightly out from magnetic center, but probably within QC tolerance (see **Figure 7**). **Figure 8** and **Figure 9** depict the K_{MS} (X) and K_{MS} symmetry range curves for the 12FHX76. The K_{MS} (X) curve is also quite symmetrical in both directions, with a small amount of coil-out (forward) offset. The K_{MS} symmetry curve shows the offset is 1 mm at the zero rest position, and only increases to 1.4 mm at the physical X_{MAX}. The 12FHX76's displacement-limiting numbers, calculated by the Klippel analyzer, were XBl at 82% (Bl decreasing to 82% of its maximum value) was 4.5 mm and for XC at 75% (compliance decreasing to 75% of its maximum value) was 2.5 mm, which means the compliance is the most limiting factor at the 10% prescribed distortion level. According to some experts, 10% may be a somewhat conservative number given the relative difficulty of perceiving THD subjectively. So, if we apply the 20% distortion criteria with Bl decreasing to 70% and compliance decreasing to 50%, then the numbers are XBl = 5.4 mm and XC = 4.6 mm.

Figure 10 shows B&C coax woofer's inductance curve

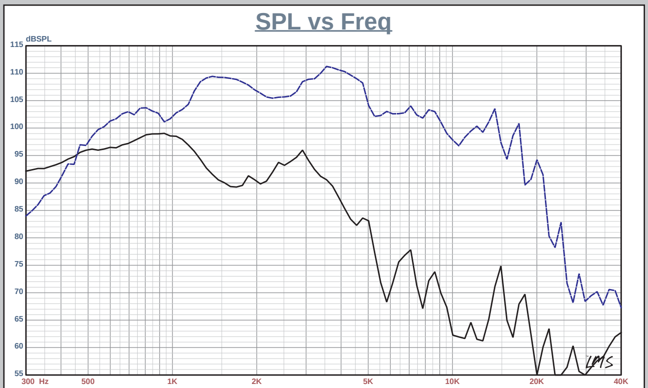


Figure 11: On-axis frequency response for the B&C 12FHX76 woofer and DE7 compression driver/horn

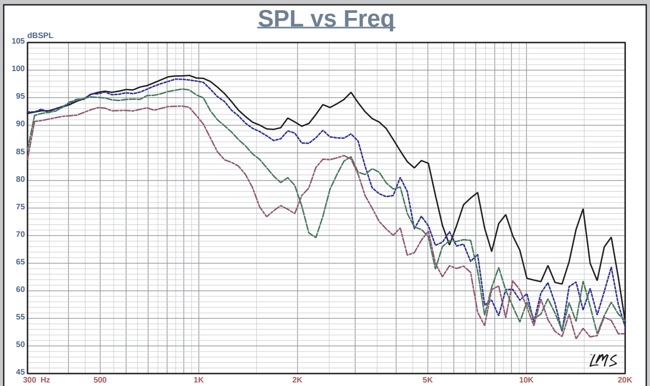


Figure 12: The B&C 12FHX76 woofer on- and off-axis frequency response (black solid = 0°; blue dot = 15°; green dash = 30°; and purple dash/dot = 45°)

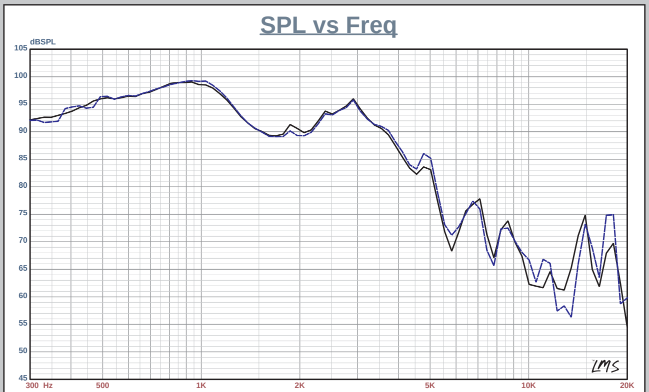


Figure 13: B&C 12FHX76 woofer two-sample SPL comparison

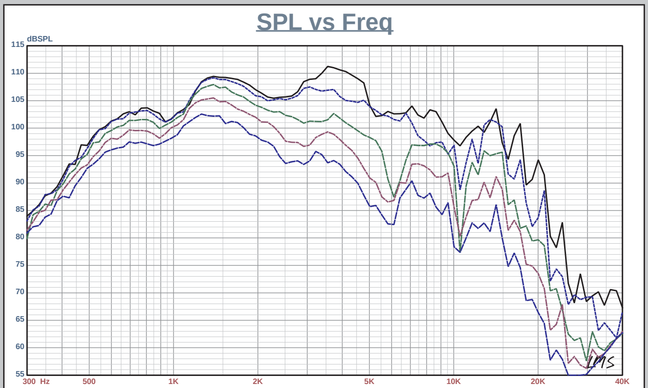


Figure 14: B&C 12FHX76 compression driver's horizontal on-and off-axis frequency response (black solid = 0°; blue dot = 15°; green dash = 30°; purple dash/dot = 45°; and blue dash = 60°)

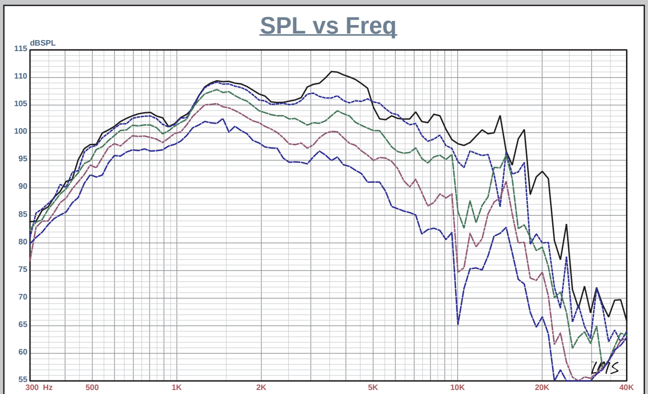


Figure 15: B&C 12FHX76 compression driver's vertical on-and off-axis frequency response (black solid = 0°; blue dot = 15°; green dash = 30°; purple dash/dot = 45°; and blue dash = 60°)

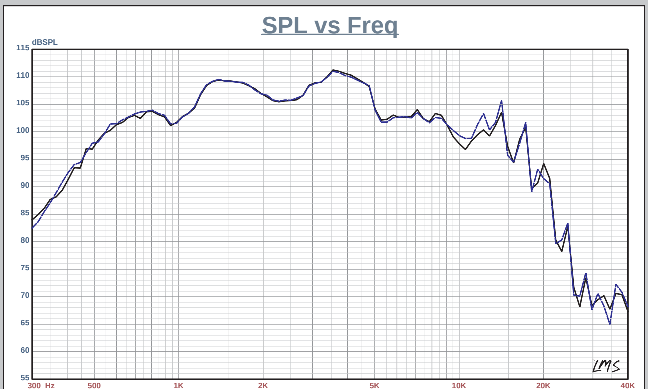


Figure 16: B&C 12FHX76 compression driver two-sample SPL comparison

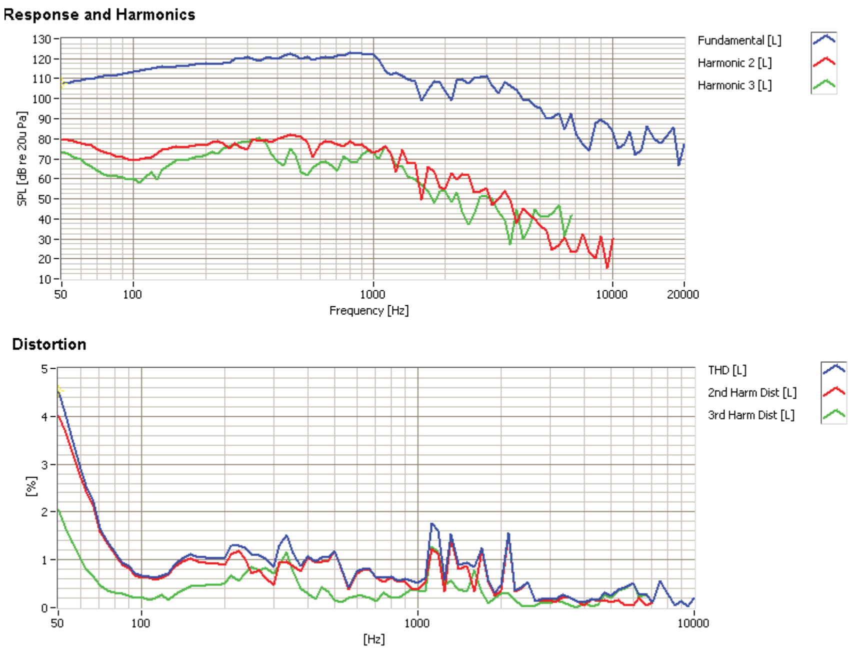


Figure 17: B&C 12FHX76 woofer SoundCheck distortion plot

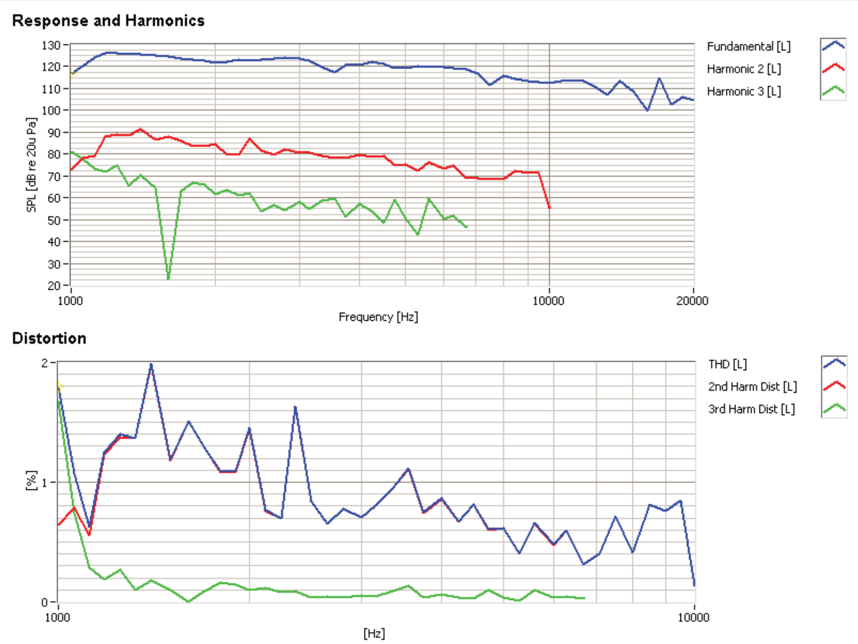


Figure 18: B&C 12FHX76 compression driver SoundCheck distortion plot

L(X). Inductance will typically increase in the rear direction from the zero rest position as the voice coil covers more pole area, unless the driver incorporates a shorting ring. Since the 12FHX76 does not incorporate a faraday shield (shorting ring) in the motor assemble, you can see the typical inductance rise for the coil-in direction of motion. However, from X_{MAXIN} to X_{MAXOUT}, the inductive change is fairly small at 0.55 mH.

Next, I mounted the B&C 12FHX76 in an enclosure that had a 15″ × 16″ baffle. I filled the enclosure with damping material (foam) and measured both the woofer and the compression driver/horn on- and off-axis frequency response from 300 Hz to 40 kHz for the woofer and compression driver/horn. This was performed at 2.83 V/1 m using a 100-point LMS gated sine wave sweep. **Figure 11** shows the 12FHX76 woofer on-axis response along with the compression driver/horn on-axis response. The woofer response has a smooth rising response to 900 Hz followed by a 6-dB breakup peak at 2.9 kHz just prior to the low-pass rolloff. For the compression driver/horn, the response is ±4.5 dB from 1 kH to 9 Hz.

Figure 12 shows the woofer on- and off-axis frequency response at 0°, 15°, 30°, and 45°. The −3 dB at 30° result with respect to the on-axis curve occurs at 1 kHz making 1 to 1.5 kHz a reasonable crossover range. B&C recommends a 1.2-kHz crossover frequency for the compression driver. **Figure 13** shows the two-sample SPL comparisons for the 12FHX76 woofer samples, both samples obviously closely matched.

Figure 14 shows the on- and off-axis horizontal frequency response out to 60° for the compression driver with the exponential 40° × 60° horn. **Figure 15** gives vertical frequency response out to 60°. **Figure 16** shows the two-sample SPL comparison, which is good throughout the entire frequency range with some minor variation above 9 kHz.

The last group of tests were performed using the Listen SoundCheck analyzer and SC-1 microphone to measure distortion and generate time-frequency plots. I used SoundCheck's software noise generator and SPL meter to set up the distortion measurement. I mounted the driver rigidly in free air and used a noise stimulus to set the SPL to 104 dB at 1 m. Then, I measured the distortion with the Listen microphone placed 10 cm from the dust cap/horn mouth. This produced the distortion curves shown in **Figure 17** for the woofer (3.2 V). **Figure 18** shows the distortion curves for the compression driver (0.7 V).

Last, I employed the SoundCheck analyzer to get a 2.83-V/1-m impulse re qsponse for both the woofer and compression driver and imported the data into the SoundMap time/frequency software. The 12FHX76 woofer's

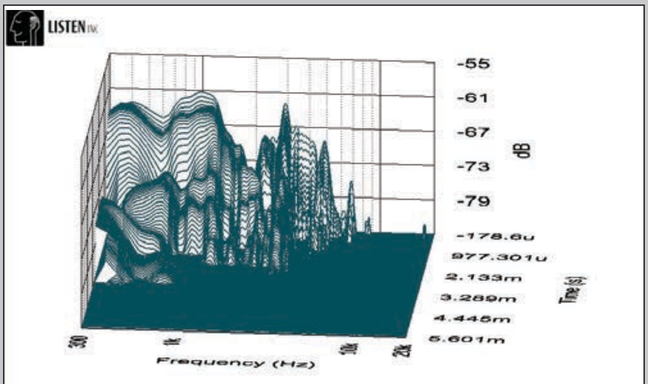


Figure 19: B&C 12FHX76 woofer SoundCheck CSD waterfall plot

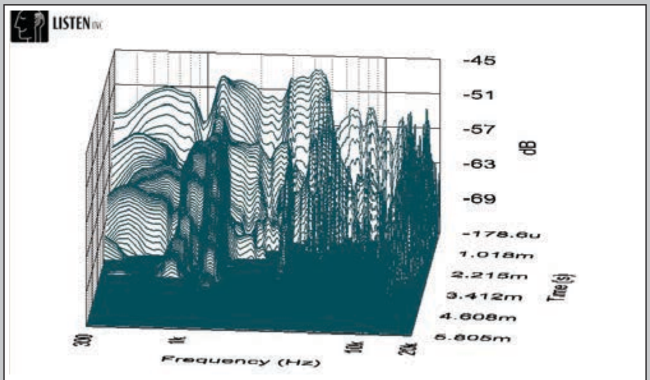


Figure 20: B&C 12FHX76 compression driver SoundCheck CSD waterfall plot

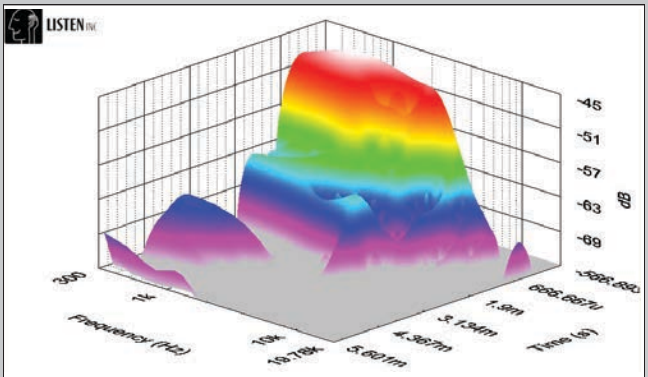


Figure 21: B&C 12FHX76 woofer SoundCheck Wigner-Ville plot

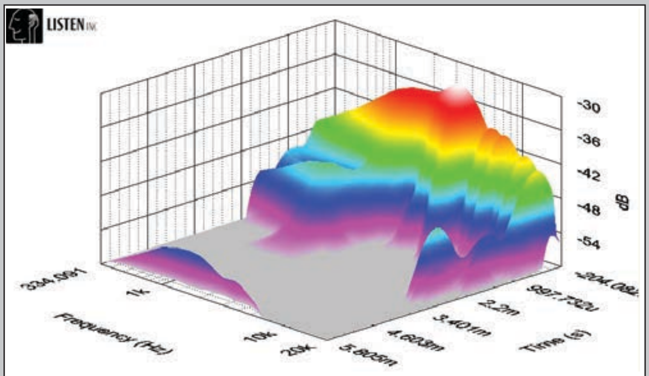


Figure 22: B&C 12FHX76 compression driver SoundCheck STFT plot

resulting cumulative spectral delay (CSD) waterfall plot is shown in **Figure 19**. The compression driver's CSD waterfall plot is shown in **Figure 20**. Last, **Figure 21** shows the woofer's Wigner-Ville logarithmic surface map (for its better low-frequency performance). **Figure 22** shows the compression driver's short-time Fourier transform (STFT). Overall, it is a well-executed coaxial driver for pro sound applications. For more information, contact B&C Speakers N.A., National US Sales Office, 220 West Parkway, Unit 11, Pompton Plains, NJ 07444; (973) 248-0955; fax (973) 248-0956; e-mail Bennett Prescott at bprescott@bcspeakers.com; or visit www.bcspeakers.com. *aX*

MEMBER PROFILE

Member Name: Ethan Winer

Location: New Milford, CT

Education: Two years college for music

Occupation: Audio engineer, technical author, professional musician, and co-owner of RealTraps, a popular acoustic treatment manufacturer

Member Status: He has subscribed to *audioXpress* for approximately seven years.

Affiliations: Ethan does not currently hold official memberships with any audio organizations.

Audio Interests: Ethan is interested in all aspects of audio and music, but especially acoustics, and how fidelity is defined.

Most Recent Purchase: A Focusrite Scarlett 8i6 USB sound card

Current Audio Projects: Ethan has just completed creating a 2.5-h music theory video course, "Basic Music Theory." (The course is available for free on YouTube at www.youtube.com/playlist?list=PLc4B83q8Dd4UiXa1ADDbwcOvIhIc1EWyN&feature=view_all.)

Dream System: He said he has his dream systems. Yes, plural. Ethan has two systems: A large home recording studio (two channel), and a 5.1 home theater in his living room.


Ethan Winer

He said the key to excellence with both systems is more in the acoustic treatment of the rooms than the specific gear.