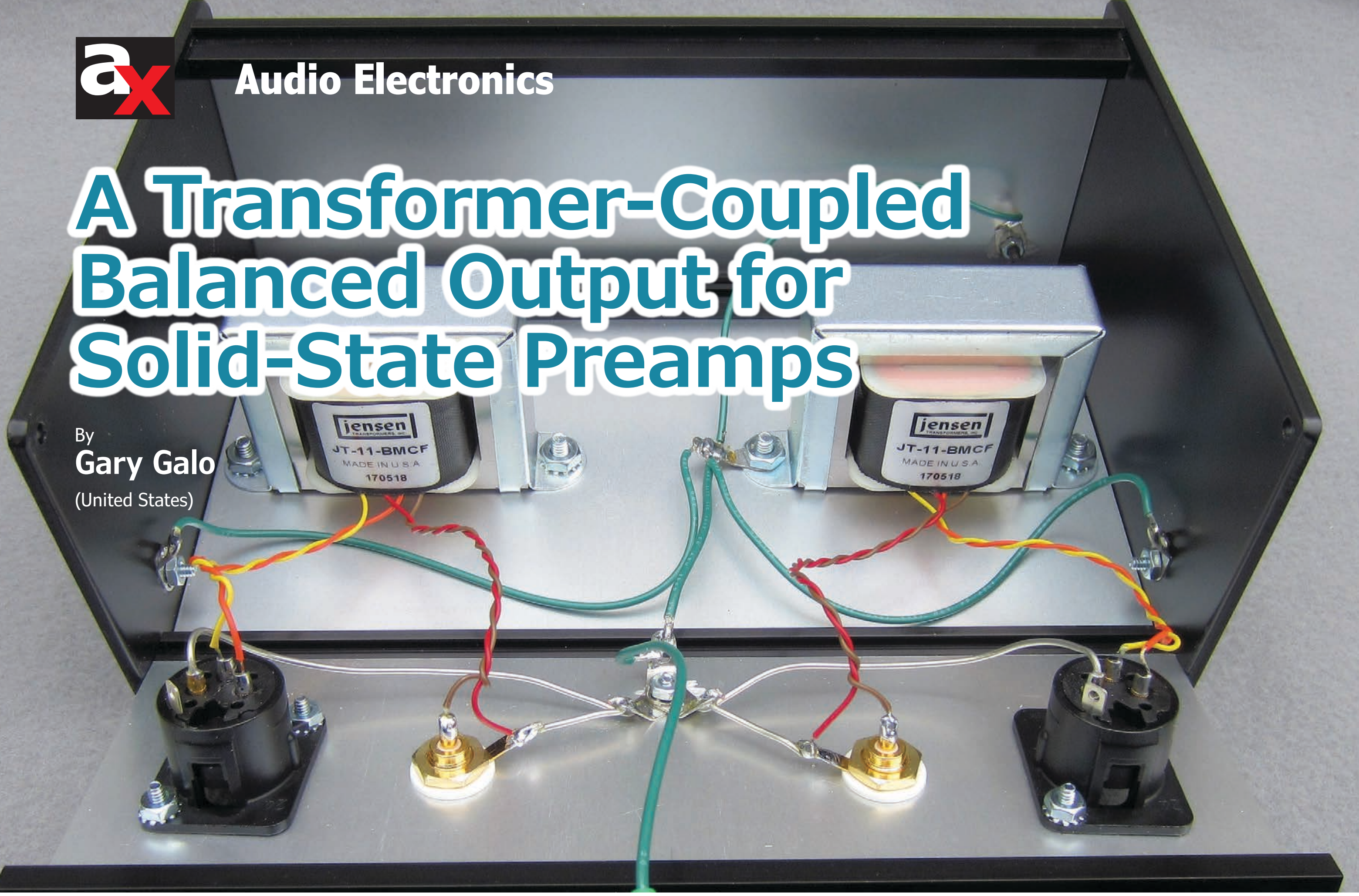

A Transformer-Coupled Balanced Output for Solid-State Preamps

By
Gary Galo
(United States)

Our longtime contributor Gary Galo explores the differences between balanced interfaces and unbalanced interfaces. Then, he explains why he selected Jensen transformers for his own high-end system.

Balanced interfaces have long been standard practice in the pro-audio world, both for microphone-level and line-level signals. Before explaining the difference between unbalanced and balanced interfaces, let's clarify two often-misunderstood terms: phase and polarity. To understand the difference, consider the fact that musical waveforms are normally asymmetrical. The positive-going portion of the waveform is rarely a mirror image of the negative-going portion. If you view two continuous sine waves, or other test tones, on an oscilloscope, the symmetrical nature of the waveforms makes it impossible to distinguish between a phase difference and a polarity difference. The asymmetrical waveform in **Figure 1** makes this much easier to visualize. Phase refers to the time relationship between two audio signals. In the upper illustration shown in Figure 1, waveform B lags behind waveform A by 180°. Conversely, waveform A leads waveform B by 180°. This is a phase difference. In the lower illustration shown in Figure 1, waveform B is inverted in polarity relative to waveform A. This is what occurs when you reverse the leads to one of the loudspeakers in your stereo system. We normally refer to the two speakers as being out-of-phase, but this is technically incorrect—they're really of opposite polarity.

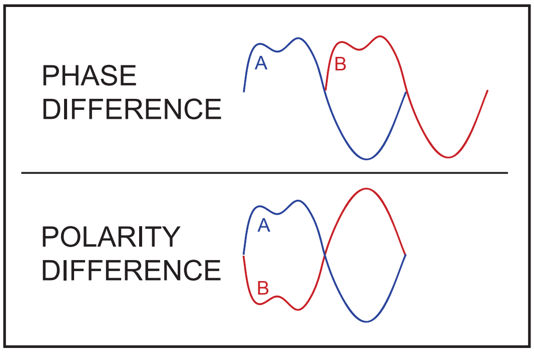

Figure 1: The difference between phase and polarity is best illustrated using asymmetrical waveforms. The upper illustration shows a phase difference—waveform B lags waveform A by 180°. The two waveforms in the bottom illustration are of opposite polarity.

Balanced lines are preferred in professional audio applications because of their superior noise rejection. **Figures 2–5** illustrate the concepts behind unbalanced and balanced interfaces. They are not intended to be complete, working circuits. For the purposes of illustration, I've treated each interface as unity-gain. What's important here are the relative polarities of the audio signals and, especially, the noise. As additional reading, I recommend Jensen Transformers' Application Note AN-003, "Interconnection of Balanced and Unbalanced Equipment," by long-time company president Bill Whitlock. Whitlock retired from Jensen in 2014, but the new parent company, Radial Engineering, has retained him as a consultant. I'll refer to that document several times in this article, along with other correspondence I've had with Whitlock.

Figure 2 shows an unbalanced interface between an audio source and a load. The source could be a preamplifier or mixer, and the load might be a power amplifier or audio recorder. The cable connecting the two pieces of equipment consists of a single signal carrier surrounded by a shield. The audio source has a single-ended output, which feeds the audio along the center conductor to a single-ended input in the receiver.

Unfortunately, even the best shielding is never 100% effective in preventing the center conductor from picking up electromagnetic radiation. Indeed, the shield is often the source of the noise. In AN-003, Whitlock notes: "The inherent weakness of unbalanced interconnections is that the shield, which is also a signal conductor, is a path for power-line related currents that always flow between equipment grounds. The voltage drop across the resistance of the shield and connectors adds directly to the signal, producing the familiar hum and buzz."

Hum and other noise picked up by the center conductor will be amplified by the receiving equipment along with the audio fed from the source. The longer the cable, the worse the problem. This can be especially problematic with microphone-level signals, which are typically only a few millivolts. Unbalanced interfaces are completely unacceptable for professional, microphone-level interfacing, and are normally avoided even with line-level applications.

Figure 3 shows a balanced interface. The audio source feeds a pair of signal carriers from an active, differential output, which provides signals of opposite polarity to the two conductors. These opposite-polarity signals are fed to an active, differential input in the receiving equipment. The differential input receiver has both non-inverting and inverting inputs. When the opposite-polarity

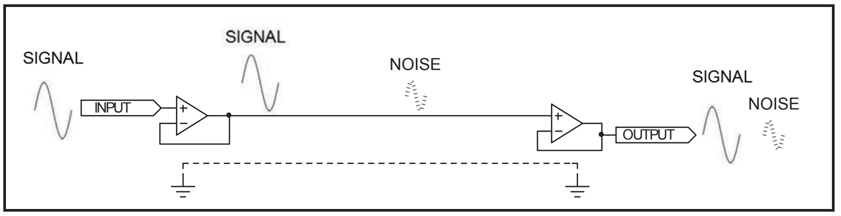

Figure 2: An unbalanced interface has a single signal carrier and a shield. Any noise picked up by the signal carrier will be passed to the receiving equipment along with the audio signal.

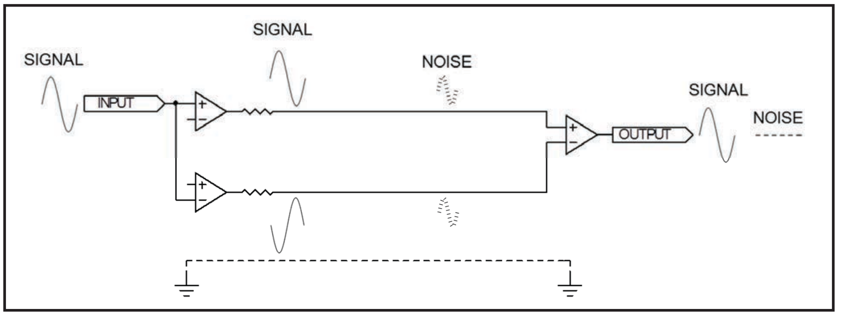

Figure 3: A balanced interface usually feeds audio signals of opposite polarity to a pair of conductors. Noise picked up by the cable will be the same polarity in the two conductors, and will cancel when connected to the differential input in the receiving equipment. Good common-mode rejection is dependent upon matched impedances in the two audio lines, and not signal symmetry. A balanced interface can be made with discreet components, IC op-amps, or various IC line drivers and receivers designed for that purpose.

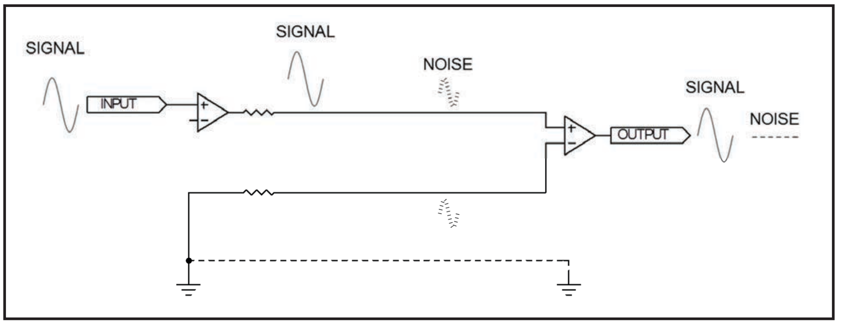

Figure 4: A true balanced line can be made with only one signal carrier, but still requires two conductors. Noise will still cancel as long as the impedances of the two conductors are matched. This scheme has been used in applications where professional operating levels are not essential, and is often incorrectly called a quasi-balanced or pseudo-balanced line.

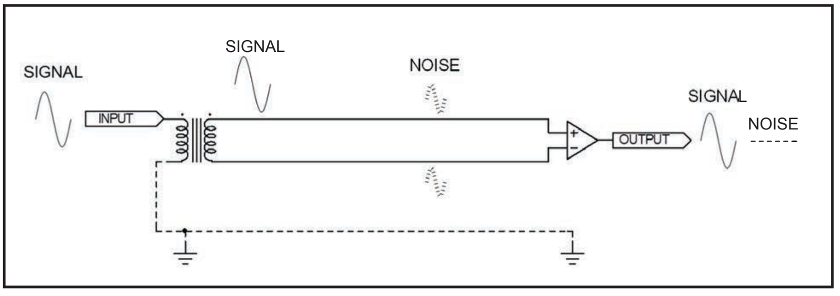

Figure 5: In a balanced interface driven by a line-output transformer, signal is present on only one end of the transformer secondary. This is due to the capacitive coupling between the windings of the transformer, which holds the "low" end of the secondary at the same signal potential as the corresponding end of the primary winding. This is still a true balanced interface due to the matched impedances in the two lines. Noise will still cancel when the two conductors are connected to the differential input in the receiving equipment.

signals are fed to the differential input, they combine as though they are the same polarity. Like the unbalanced interface, the two signal carriers are surrounded by a shield. Noise picked up along the way will be the same polarity in each conductor, and is known as a common-mode signal. Since these same-polarity noise components are fed to the differential input, they combine as though they are of opposite polarity, resulting in cancellation of the noise. The ability of a balanced interface to cancel noise is known as common-mode rejection. Active balanced interfaces can be designed around discrete components, IC op-amps, and specialized line-driver and line-receiver chips.

In 2005, Whitlock gave a superb presentation on grounding and system interfacing at the New York convention of the Audio Engineering Society. I wrote a detailed report on his presentation for the January 2007 issue of *audioXpress*. One point Whitlock drove home was that in order to qualify as a balanced interface, the two conductors must be matched in impedance relative to ground. The more closely the impedances are matched, the better the common-mode rejection. But, he also noted that the two conductors need not both carry the audio signal.

Balanced Lines

Figure 4 shows an active, balanced interface where only one conductor carries the audio signal. At the source component, the second conductor is grounded through a resistor. The resistor value is selected to ensure that the source impedance of this conductor is the same as that of the active device driving the signal carrier. Normally, this resistor will be the same value as the resistor in series with the output of the active device. Noise picked up by the two conductors will cancel at the differential input, as before. The only disadvantage of having just one signal carrier is a 6 dB reduction in combined signal level, so they're normally not used where professional operating levels are required. However, they'll be fine in most home audio systems. This type of interface has been used by at least one manufacturer of pro-audio mixers for auxiliary sends, and even main outputs on their least expensive models. It's sometimes called a "quasi-balanced" or "pseudo-balanced" interface, but those terms are misleading, if not downright incorrect. As Whitlock points out in AN-003, this is a true balanced output, since it provides correct impedance matching of the two conductors, which is all that's necessary for noise rejection.

A balanced interface can also be made using transformers. Figure 5 shows a balanced interface using a line output transformer feeding an active, differential input receiver. Intuitively, one would think that a line output transformer would feed symmetrical audio signals to the two conductors, equal in level but of opposite polarity. However, this isn't the case. The primary winding of a line output transformer is normally driven by applying audio signal to the "high" side of the primary. The "low" side is normally connected to signal ground. If you put your oscilloscope probe on the "high" side of the transformer secondary—the output—you'll see the audio signal at full level. But, if you connect your probe to the low side, you'll see nothing. The transformer's "high" and "low" outputs appear to be floating, so how can this be?

I posed this question to Whitlock, who provided a most illuminating answer (note that Jensen color codes the "high" sides of its JT-11-BMCF transformer primary and secondary windings brown and orange, and the "low" sides red and yellow, respectively). Whitlock said, "Because it's an output type transformer, there is a relatively large capacitance between primary and secondary, 36 nF for the Jensen JT-11-BMCF. Since this capacitance is distributed uniformly across the windings, a first-order approximate equivalent circuit would see about 18 nF at each end (between BRN and ORG and between RED and YEL, for example). Therefore, with high-impedance balanced loads, the voltages at ORG and YEL will essentially be identical to those at BRN and RED—it effectively operates as a pair of coupling capacitors. Only when the load impedances (from each end to ground) are quite low (300 Ω each, for example), will the secondary voltages become symmetrical (which is not the same as balanced, contrary to widely-held belief)."

Whitlock went on to clarify the requirement for a balanced interface: "In a practical interface, this behavior is of no consequence—noise rejection in an interface does not arise from signal symmetry. When we wrote the 'informative annex' to the IEC standard 60268-3 test for common-mode rejection, we emphasized this point. What makes a balanced interface 'balanced' is not symmetrical signals, it's equal ('balanced') impedances from each leg to ground. Symmetry of signal on the two legs has advantages (more differential signal level is possible, and radiated crosstalk from an unshielded cable is reduced), but they have nothing to do with noise rejection ... and that's the reason we use balanced interfaces in the first place."

Whitlock also explained the differences between output and input transformers, which are widely misunderstood: "The most striking difference is due to the inclusion of a Faraday shield (a layer of copper foil between primary and secondary windings) in input types. When this shield is grounded (to the signal reference ground for the secondary), capacitive coupling between the primary and the secondary is virtually eliminated. This ultra-low capacitance is absolutely essential to achieving high common-mode rejection ratio (CMRR) for an input transformer.

"But there's a catch: because primary and secondary are now physically separated, some of the magnetic field generated by the primary isn't captured by the secondary—this looseness in coupling is measured as 'leakage' inductance (several mH or more is typical). In an equivalent circuit model, this inductance is effectively in series between primary and secondary. This wouldn't necessarily be a problem unless the load on the secondary has either a low resistance or a high capacitance, or both. Therefore, input transformers will exhibit severe high-frequency response losses if loaded with a high capacitance (over a few hundred pF, generally). This makes them eminently unsuited for use as an output transformer, where they may be required to drive a hundred feet of cable!

"On the other hand, output transformers are wound to put each turn of the primary in the closest possible proximity to corresponding secondary turns (multi-filar construction). This makes magnetic coupling very tight and 'leakage' inductance extremely low (often just a few µH). This makes them suitable for driving long runs of cable with little or no loss of high-frequency bandwidth. But it's this intimacy of primary and secondary that creates high capacitance between primary and secondary, and the side-effect you noted with signal symmetry," Whitlock concluded.

In Figure 5, the audio signal appears on only one conductor, just as it does in the actively-driven example in Figure 4. The transformer secondary winding provides matched impedances to each leg of the balanced line. As long as the input impedances of the differential input receiver are also matched, noise will cancel just as it does in Figure 3 and Figure 4. At 60 Hz, a high-performance transformer can have a common-mode rejection ratio in excess of 100 dB. A line-input transformer could be substituted for the active, differential input. High-performance line-output transformers are capable working at professional operating levels, given sufficient input signal from the active source.

Why Balanced?

Most consumer audio equipment is connected with unbalanced lines, using single-conductor shielded cables and RCA connectors. The short cable runs encountered in a domestic environment hardly ever cause audible noise, so audio manufacturers have traditionally found balanced lines unnecessary. In recent years, balanced connections on stereo preamps and power amplifiers have become more common. Most modern audio power amplifiers with balanced inputs have true differential input stages, so optimum performance is not dependent on signal symmetry at the balanced input. The issue is noise. Modern audio power amplifiers have lower inherent noise levels than their predecessors, and will perform best if they are fed from a balanced source.

Benchmark is an example of a manufacturer that offers only balanced XLR inputs on its superb AHB2 power amplifier. This ultra-quiet amplifier has a signal-to-noise ratio of >130 dB across the audio spectrum, and an input CMRR of 80 dB up to 1 kHz, and 65 dB at 20 kHz. The limiting factor, as far as noise is concerned, will be the source equipment and the interface between that equipment and the AHB2. Benchmark strongly recommends a balanced interface in order to make the most of this amplifier's exceptional noise performance.

Whitlock offered these observations on signal symmetry, noise and related issues in power amplifiers: "For 'most' power amplifiers (the ones designed by engineers who understand that a balanced signal is not necessarily symmetrical), the answer is that it doesn't matter. However, there are quite a number of power amplifiers whose design is 'balanced' (as if it were a feature) in that the signals on pins 2 and 3 of the input XLR feed two identical, single-ended amplifiers that drive the push-pull output tube grids (every one of these miscreants I've seen is a vacuum-tube design). Most importantly, there is no differential amplifier to eliminate the common-mode input voltage. If such amplifiers are fed by a balanced line with no signal on, say, pin 3, one output tube fights with the other. Worse yet, if there is common-mode voltage at the XLR, both output grids see it as in-phase ... which causes abnormally high peak plate currents since the primary of the output transformer is essentially a short circuit when driven with the same signal on both sides of its center-tap. The result is very high and awful-sounding distortion. The cure should be a redesign by the manufacturer, but it can be cured by an input transformer having a center-tapped secondary (Jensen makes an ISO-MAX for this) inserted at the amplifier input. It not only removes the common-mode signal, but produces the phase inversion that the designer apparently assumed was a required characteristic of 'balanced' signals. This myth ruins designs more often than you might think ... I've seen it on some very expensive gear!"

Back in the days when we played only analog sources, our audio systems were largely free of digital noise. But, digital players, digital servers, and outboard digital-to-analog converters (DACs), can radiate digital noise that will be picked up by analog interface cabling. Switching-mode power supplies, which are becoming more prevalent in professional and consumer audio equipment, can also radiate noise, and sometimes put noise back out on the power cables that feed them. Noise from digital equipment and switching power supplies can begin at audible frequencies, and often extends into the radio-frequency spectrum. It's normally low enough in level to be inaudible as noise from your loudspeakers. But, high-frequency noise can contaminate audio signals, resulting in a loss of detail and even grungy sound. Balanced interfaces can help alleviate these problems.

Belden engineer Steve Lampen has written an interesting article on the rejection of EMI and RFI by balances lines, which is available on Belden's website (see Resources). Lampen describes a situation where the RFI from a large antenna farm for San Francisco, CA-area TV transmitters rendered a nearby audio system unusable. Converting the equipment interfaces to balanced lines, using "expensive transformers," solved the problem—"clean as a whistle," he notes.

In 2016, Paul McGowan, CEO of PS Audio, offered a series on balanced interfaces in his daily e-mailing "Paul's Posts." This multi-part series ran between November 20 and December 4 of that year. I've provided the link to the first part in the "Resources" section—at the end of each section you can click on the arrow to advance to the next one. McGowan began by noting that, like most of us, he had long used unbalanced interconnects in his system even when balanced inputs and outputs were available on the equipment he manufactured. After trying balanced cables, he became convinced that "they just sound better." McGowan offers his own, always-interesting perspectives on this issue.

I have my Audio Concepts Sapphire III/Sub-1 loudspeaker systems passively bi-amped with a pair of AHB2 amps. When I ran my Benchmark power amps from an unbalanced source, I never heard any audible noise from my loudspeakers—no hum, buzz or other anomalies. My system was audibly silent under no-signal conditions. Having used them both ways, I totally agree that they sound better when operated in the balanced mode.

Balanced Output Choices

Active interfaces using integrated circuits (ICs) can be built for very low cost, and have become ubiquitous in professional audio equipment. These include circuits designed around IC op-amps, and specialized line-driver and line-receiver chips. If you're designing a preamplifier from scratch, or have the ability to modify one internally, there are many options for adding a balanced line driver to your preamp. Walt Jung offered several balanced line driver topologies in the two applications handbooks published by Analog Devices in 1993 and 2005. Fortunately, these invaluable volumes are now available as downloads on its website (see Resources).

Several manufacturers of audio ICs have made balanced line driver and receiver chips. These include

Analog Devices' SSM series, and Texas Instruments' (TI) DRV and INA series, along with THAT Corp.'s OutSmarts 1606 and 1646 balanced line drivers and InGenius 1200-series of balanced line receivers. I wrote two articles on THAT's chips for *audioXpress*—those articles are still available (see Resources). TI offers two fully-differential audio op-amps, the LME49724 from its National Semiconductor line, and the more recent OPA1632, from its Burr-Brown line. The OPA1632 has impressive specs, including a slew rate of 50 V/µSec, a gain-bandwidth product of 180 MHz, a THD of 0.000022%, and noise of 1.3 nV/√Hz. OPPO Digital uses the OPA1632 for the balanced outputs on its UDP-205 digital player (see *audioXpress*, November 2017). On paper, at least, the OPA1632 may be the best single-IC solution for active, high-performance balanced outputs.

The above choices all provide signal symmetry in addition to impedance-matched balanced interfacing. If professional operating levels are not required, signal symmetry probably isn't either. In these cases, the topology show in Figure 4 will work just fine. Whitlock highly recommended this option in our correspondence, and describes its implementation in AN-003. Note that the source impedance provided to XLR pin 3 must precisely duplicate the preamp's active output.

In addition to the output series resistor, some preamps may have an output coupling capacitor terminated with a load resistor. This should be duplicated for the other leg of the balanced line, as shown in the illustration on page 3 of AN-003. The added resistor and other components, if needed, should be mounted as close to their counterparts at the line stage output as possible, and connected to signal ground close to the active circuitry. I would avoid the temptation to connect them to any convenient chassis or signal ground on or near the rear panel. PC trace or other ground lead inductance and resistance between the added components and the active circuitry's signal ground will change the impedance, unbalancing the line.

Transformer Option

There will be instances where it's not possible to mount XLR connectors, additional passive components, or an active balanced line driver, in an existing preamp chassis, due to lack of space. It's certainly possible to house active circuitry in an external enclosure, but this will require building a power supply, which may mean another power transformer, rectifiers, regulators, and AC line cord. If you're lucky, you may be able to tap suitable power supply voltages in your preamp, but I would still recommend local regulation in the external enclosure. If you're using the method shown in Figure 4, I don't recommend housing the extra components in an external enclosure, for the reasons cited above.

If this sounds a bit cumbersome, there's a much simpler solution that can offer outstanding performance: a line-output transformer. A high-quality line-output transformer can offer performance rivalling active circuitry, but there are disadvantages, namely physical size, weight, and cost. High-performance audio transformers aren't cheap, and you definitely get what you pay for. My goal was to build an outboard box that could be connected to the unbalanced outputs of any solid-state stereo preamp with a sufficiently-low output impedance, using a very short interconnect. After consultation with Dave Hill, General Manager at Jensen Transformers, I decided on the company's very-best line-output transformer, the JT-11-BMCF mentioned earlier in this article.

Physically, the JT-11-BMCF is Jensen's largest output transformer. It has an 80% nickel alloy lamination core, which provides very low distortion at low frequencies. It will also drive 600 Ω loads, though this should not be of any concern in the modern audio world.

As Whitlock pointed out in his 2005 seminar, 600 Ω impedances are a holdover from early telephone practice. Modern audio circuits are designed with low output impedances and high input impedances, making performance with 600 Ω loads irrelevant. Nonetheless, manufacturers still feel the need to make sure their products will perform into 600 Ω loads, despite the fact that this ceased to be an issue decades ago.

Grounding and Capacitive Loading

Before beginning construction, I had several questions for Hill. The first concerned grounding. Should signal ground from the unbalanced input be tied to pin 1 on the balanced output? Or, should the input RCA jacks' shields be connected only to the lower end of the transformer primary, and not tied

Parts List

(2) Jensen JT-11-BMCF Line-output transformers (Jensen Transformers, Inc.; Markertek)

(1) Connectronics CTX-MC-6A Aluminum Project Cabinet (Markertek)

(2) Neutrik NC3MD-L-1-B, 3-pin male XLR connectors (Markertek)

(2) D.H. Labs CM-R1 Chassis-mount RCA Jacks (D.H. Labs; Parts Connexion)

Miscellaneous: Machine screws, nuts, lock washers, and ground lugs

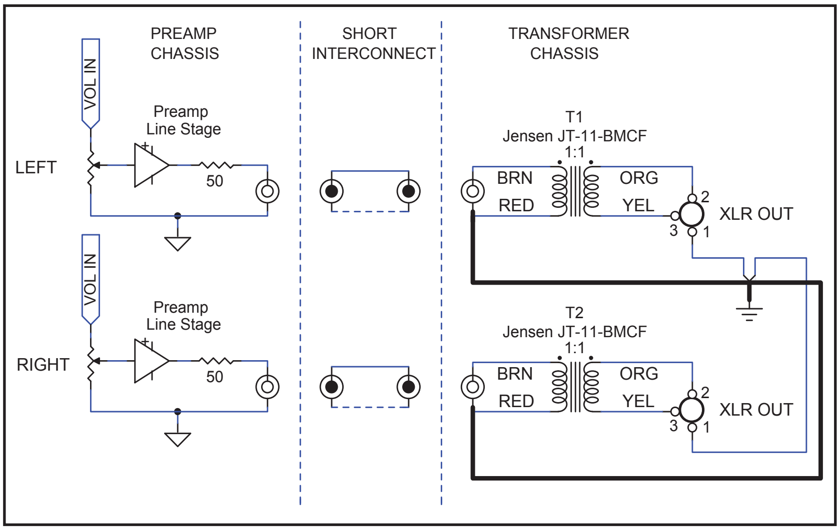

Figure 6: This is the complete circuit showing the unbalanced source, short interconnect, and the external unbalanced-to-balanced transformer. The JT-11-BMCF is Jensen's finest line-output transformer.

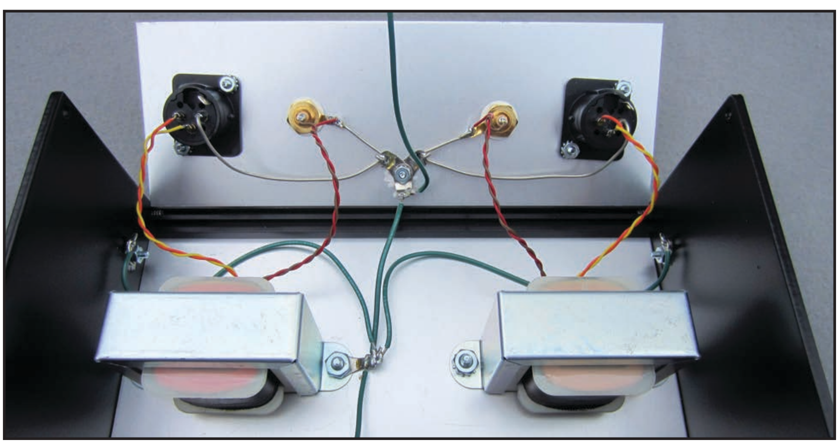

Photo 1: This is an inside view of the Connectronics CTX-MC-6A enclosure housing the two Jensen JT-11-BMCF line-output transformers. The star ground is in the center of the rear panel, along with the D.H. Labs RCA jacks and Neutrik XLR connectors.

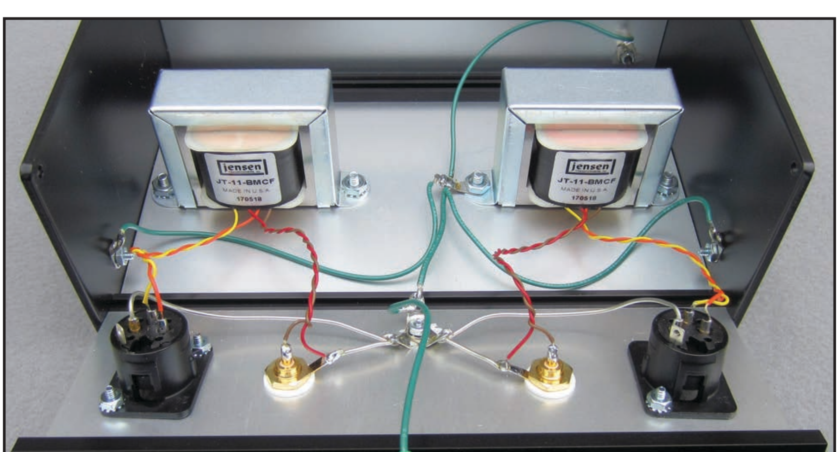

Photo 2: Here's another inside view of the enclosure. Connecting the top, bottom, and sides of the enclosure ensures that all pieces are at ground potential. The anodizing should be scraped off wherever a ground lug is used.

to chassis ground and pin 1 of the output XLRs? I was thinking of connecting the I/O grounds through a "Ground Lift" switch that would allow it to be used either way.

Hill responded as follows: "You bring up some important questions regarding grounding when using transformers. The rules are different when you are mounting a transformer in an external box than they are when you install them directly inside the equipment. The balanced-output cable's shield that connects to Pin 1 of the external box's output XLR's should also be connected through that box back to the chassis of the source equipment. To do this, the Pin 1 connection inside the box should carry over to the input RCA's sleeve connection, so that Pin 1 has a hard connection all the way through to the source equipment's chassis. If you are using RCA connectors that are isolated from the chassis, then you should also connect the metal box to the input RCA's sleeve, so the box itself gets grounded back to the source equipment's chassis. In your application, a ground lift switch would not be necessary."

Most audio preamplifiers protect the line stage from the effects of capacitive loading, which can cause oscillation in audio circuitry, particularly IC op-amps. A low-value resistor in series with the preamp's output is usually sufficient. Jensen makes a parallel L/R network for this purpose, the JT-OLI-3.

The JT-OLI-3 is a 39 Ω resistor with a coil of enamel-coated wire wound around the resistor body to form the parallel inductor. The impedance of the network is 0.3 Ω across the audible spectrum, but rises to around 40 Ω in the RF region. In its datasheet, Jensen recommends using two of these networks with the line-output transformer—one in series with the signal input to the primary winding, and the other in series with the ground side of the primary.

I asked Hill if this network was necessary for my project and he assured me that it wasn't. The Jensen isolation network was designed to protect output op-amps from the effects of very long cable runs, which can be several hundred feed in professional applications. With the cable runs encountered in most home installations, the preamp's single internal series output resistor is all that's necessary.

In high-end, solid-state designs this output resistor may be anywhere from 20 to 100 Ω, but in cost-effective products I've seen values as high as 475 Ω. In my own preamp, this resistor is 50 Ω. I asked him about the effect of higher source impedances on the performance of these transformers.

Photo 3: This is the rear view of the enclosure, showing the unbalanced RCA inputs and the balanced XLR outputs.

Hill said, “The resistor value does have a very minor effect on the low frequency response, but only down so low we’re not able to even measure it. The 80% nickel alloy laminations in the JT-11-BMCF are the least sensitive to source impedance, when compared to 50% nickel alloy laminations. Our standard recommendation for the source impedance driving our 80% nickel alloy transformers is to keep it under 200 Ω. With 50% nickel alloy, we recommend keeping it under 100 Ω. With both types, the lower the source impedance, the lower the measurable THD will be at 20 Hz.”

Although high-performance solid-state preamps generally have output impedances that are well within the range recommended by Jensen, there are also tube preamps that meet these requirements. Some tube preamps have output impedances higher than 200 Ω. Check the manufacturer’s specifications on your particular preamp to be sure.

I also asked Hill about the physical mounting of the transformers in a stereo application, to minimize crosstalk. He notes: “Our engineer said that mounting them end to end would be best. In cases where they have to be mounted side by side, we recommend mounting one at a 90° angle to the other, if space permits, to minimize the chance of crosstalk between the two.

Crosstalk becomes a concern when the transformers are being driven hard enough to approach saturation. 1% THD at 20 Hz is where we spec our transformers to have their saturation point. On the JT-11-BMCF that point is +27 dBu (with a 0 Ω source). With a 50 Ω source, that point moves down a bit to around +25 dBu. So your preamp’s output section would have to be able to produce a signal level above +20 dBu at 20 Hz to be able to drive the output transformers hard enough towards saturation." It's reassuring to consider that the line stages of most consumer preamplifiers will never even approach the level required to saturate these transformers.

Hill added, "Also, we recommend that you tightly twist the brown and red primary wires together, and the orange and yellow secondary wires together, trimming them to the length you need without leaving a lot of excess, and then untwist the ends only enough to make your connections. Don't twist the brown/red & orange/yellow bundles together; leave them as separate twists. Twisting the two bundles together will capacitively couple the primary and secondary windings together at high frequencies, which will defeat the isolation properties of the transformer."

For those who might want to fit a pair of these transformers into an existing preamp chassis, Hill offered the following advice: "The more important concern when mounting our Jensen output transformers into a piece of gear is to try and keep them physically away from the internal power supply section to avoid magnetic hum pickup."

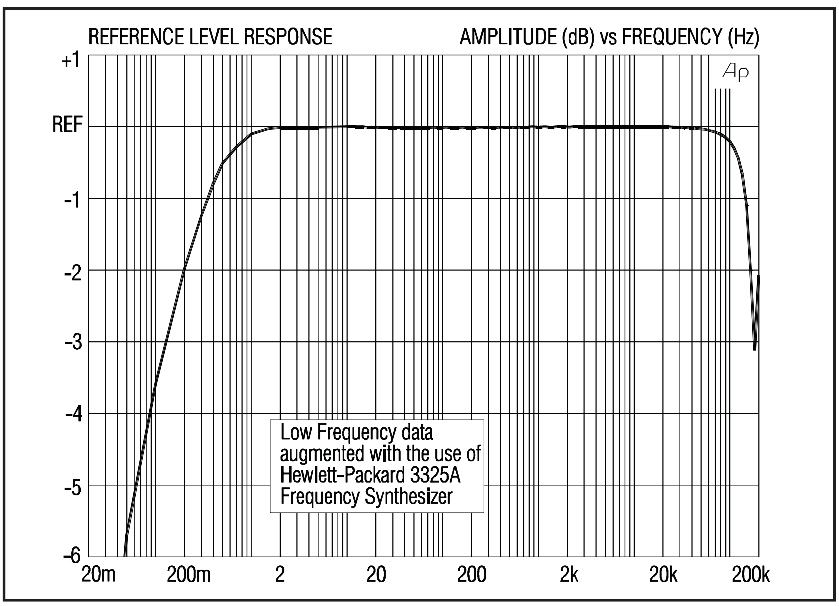

Figure 7: This is Jensen's frequency-response graph for the JT-11-BMCF line-output transformer. Jensen specifies ultimate -3 dB points of 0.15 Hz and 15 MHz. (Image courtesy of Jensen Transformers, Inc.)

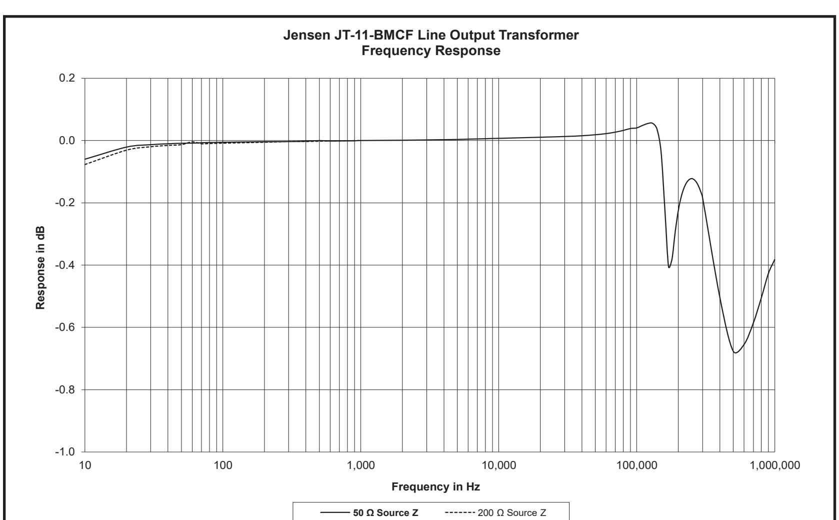

Figure 8: The solid line is the measured response of the JT-11-BMCF transformer with a source impedance of 50 Ω, plotted from 10 Hz to 1 MHz. From 20 Hz to 20 kHz the response is flat ±0.016 dB. The dashed line shows the response below 1 kHz with a source impedance of 200 Ω. The additional roll-off at 20 Hz is only 0.07 dB.

Construction

For this project, I used one of the Connectronics MC-series aluminum project boxes, readily available from Markertek. The CTX-MC-6A is exactly the size I needed—it's 8" wide, allowing enough physical spacing between the transformers to minimize any crosstalk. **Figure 6** shows a schematic diagram of the complete system. A typical unbalanced solid-state preamp line stage is shown on the right, with an output impedance of 50 Ω. Short, unbalanced interconnects in the center connect the preamp's outputs to the external transformer chassis.

My interconnects are 12" long, which I made myself. A half meter is usually the shortest you can buy ready-made, which should be fine. The input RCA grounds and pin 1 of the output XLR connectors are all tied to a single, star ground on the rear panel. I recommend using RCA jacks that are insulated from the chassis. If you allow the RCA jacks to contact the chassis, you'll defeat the star ground.

Photo 1 and **Photo 2** show inside views of the transformer box. The side pieces of the Connectronics enclosures are painted; the remaining four pieces are anodized. In order to ensure that the entire enclosure is at ground potential, I recommend a ground lug on each piece, with wires tying the pieces together. Use the star ground point to connect the rear panel to the other pieces.

Be sure to scrape or sand the paint and anodizing off of each piece, where the ground lug is mounted. I used a push-on connector to connect the ground lug on the top plate, which allows easy removal and reinstallation. I prefer D.H. Labs CM-R1 chassis-mount RCA jacks and Neutrik NC3MD-L-1-B, 3-pin male XLR connectors, but builders can certainly choose their personal favorites. **Photo 3** shows the rear panel with the RCA inputs and XLR outputs.

Performance

Figure 7 shows the frequency response graph published in the Jensen datasheet. The response is ruler-flat from 20 Hz to 20 kHz. On the low end, the -3 dB point is 0.15 Hz. The top end shows a -3 dB point just below 200 kHz, followed by a rise above that frequency. This transformer is an ultra-wide bandwidth design, with Jensen specifying the ultimate −3 dB points at 15 MHz. **Figure 8** shows the response I measured, from 10 Hz to 1 MHz, with both 50 and 200 Ω source impedances. With a 50 Ω source Z, the response is −0.006 dB at 10 Hz. With the source impedance at 200 Ω, this drops to −0.077 dB, a negligible difference. From 20 Hz to

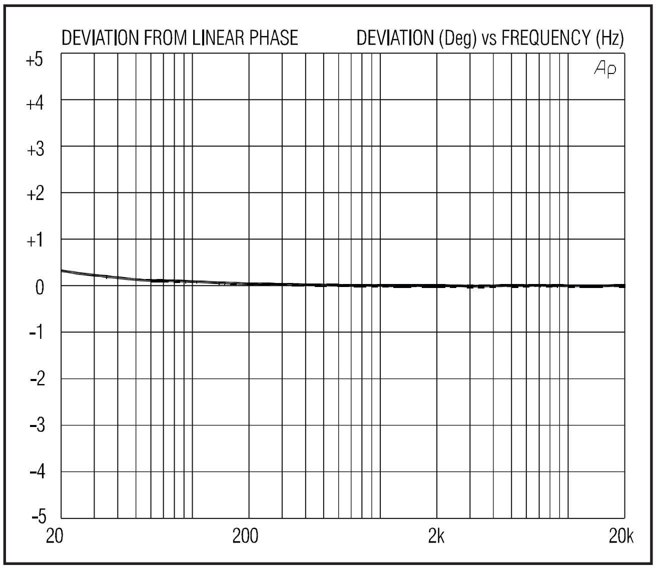

Figure 9: Extremely low deviation from linear phase is a hallmark of Jensen's audio transformers. The JT-11 BMCF is virtually flawless to 20 kHz, and has only a slight deviation of around 0.3° at 20 Hz. (Image courtesy of Jensen Transformers, Inc.)

Figure 10: This shows the square wave response of the Jensen JT-11-BMFC transformer at 20 Hz (top), 1 kHz (middle), and 20 kHz (bottom), all with a 50 Ω source impedance and a 10 kΩ load, at a level of +4 dBu. The excellent performance reflects the transformer's wide bandwidth and linear phase response.

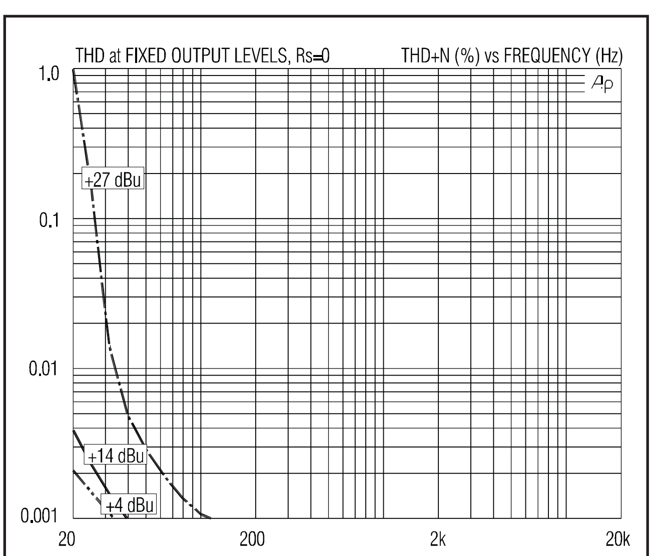

Figure 11: This graph shows total harmonic distortion (THD) of the Jensen transformer at levels of +4, +14, and +27 dBu. THD is below 0.001% across most of the audio band. (Image courtesy of Jensen Transformers, Inc.)

Resources

G. Galo, "Grounding and Shielding Seminar is Highlight of 2005 AES Convention." *audioXpress*, January 2007.

——, "New York AES 2007 – THAT Seminar," *audioXpress*, June 2008, www.thatcorp.com/datashts/Galo_AES_2007_Report.pdf

——, "THAT's Balanced Line Drivers and Receivers: Getting the most from these high-performance chips," *audioXpress*, June 2010, www.audioxpress.com/article/getting-the-most-from-that-s-balanced-line-drivers-and-receivers

——, "OPPO Digital UDP-205," *audioXpress*, November 2017, www.audioxpress.com/article/oppo-digital-udp-205-review-a-4k-ultra-hd-audiophile-blu-ray-disc-player

S. Lampen, "Balanced Lines," Belden, July 2012, www.belden.com/blog/broadcast/balanced-lines.

P. McGowan, "Maintaining balance," PS Audio, 2016, www.psaudio.com/pauls-posts/maintaining-balance.

"OPA1632 and LME49724 Fully-Differential Audio Op-Amps," Texas Instruments, www.ti.com.

"Op Amp Applications Handbook, 2005," www.analog.com/en/education/education-library/op-amp-applications-handbook.html.

"System Applications Guide, 1993," Analog Devices, www.analog.com/en/education/education-library/system-applications-guide.html.

Sources

D.H. Labs | www.silversonic.com

Jensen Transformers, Inc. | www.jensen-transformers.com

Markertek | www.markertek.com

Parts Connexion | www.partsconnexion.com

About the Author

Gary Galo retired in 2014 after 38 years as an Audio Engineer at The Crane School of Music, SUNY at Potsdam, NY. He now works as a volunteer in the Crane Recording Archive doing preservation, restoration, and digital transfer of vintage Crane recordings. He is also a Crane alumnus, having received a BM in Music Education in 1973 and an MA in Music History and Literature in 1974. Gary is a widely-published author with more than 300 articles and reviews on both musical and technical subjects, in over a dozen publications. Gary has been writing for audioXpress and its predecessors since the early 1980s. He has been an active member of the Association for Recorded Sound Collections (ARSC) since 1989, and a frequent recording and book reviewer for the ARSC Journal. He has given numerous presentations at ARSC annual conferences, many of which have been published in the ARSC Journal. He was the Sound Recording Review Editor of the ARSC Journal from 1995-2012, and co-chair of the ARSC Technical committee from 1996-2014. Gary has also published numerous book reviews in Notes: Quarterly Journal of the Music Library Association, written for the Newsletter of the Wilhelm Furtwängler Society of America, Toccata: Journal of the Leopold Stokowski Society, and he is the author of the "Loudspeaker" entry in The Encyclopedia of Recorded Sound in the US. He has also written several articles for Linear Audio. He is a member of the Audio Engineering Society, the Boston Audio Society, and the Société Wilhelm Furtwängler.

20 kHz the response is flat ±0.016 dB. A slight high-frequency rise peaks at +0.06 dB at 130 kHz before rolling off. The discrepancy between Jensen's graph and mine above 100 kHz is due to the different source impedances used in the measurements. Jensen used the isolation network discussed earlier, which has a reactive component at very high frequencies. I used a generator with a 50 Ω resistor in series with the signal output.

Linear phase response has always been a hallmark of Jensen's transformers. **Figure 9** shows the deviation from linear phase for the JT-11-BMCF transformer. The deviation is 0° over most of the audio spectrum, and has only a slight rise of +0.3° at 20 Hz. Square wave performance shows the benefits of linear phase response and wide bandwidth.

Figure 10 shows the square wave response I measured at 20 Hz (top), 1 kHz (center) and 20 kHz (bottom), with a 50 Ω source impedance and a 10 kΩ load, at a level of +4 dBu. This is virtually flawless performance. You'd be hard-pressed to do better with an active circuit. Finally, **Figure 11** is Jensen's plot of total harmonic distortion (THD), at professional operating levels of +4, +14, and +27 dBu (0 dB = 0.775 VRMS). THD is well below 0.001% above 100 Hz, rising at the lowest frequencies. Operating levels with consumer audio equipment will typically be lower than +4 dBu, where the THD is 0.002% at 20 Hz.

How does it sound? Very little, in my view. The Jensen JT-11-BMCF transformers are extremely transparent. The sound is clean, quiet, and detailed, with excellent extension and definition on both ends of the audio spectrum. As I noted earlier, the only real disadvantage is cost. But, these transformers will sonically outperform most single-chip balanced line drivers, including the THAT 1600 series. I have not had a chance to directly compare them to the TI OPA1632 fully-differential op-amps, but will probably do so in the future.

Readers who own power amps with balanced inputs, but who've been unable to take advantage of them, will find balanced interfaces a very worthwhile sonic upgrade. After living with my own preamp driving my Benchmark AHB2 amps in balanced mode, I could never go back to an unbalanced interface. If you have a high-end system saddled with an unbalanced preamp-to-power amp connection, the Jensen transformers offer an excellent solution to the problem.

Author's Note: I am grateful to Bill Whitlock and Dave Hill for the invaluable information they provided during the preparation of this article.