KIT REVIEW

PHONES–01 Headphone Amplifier

Reviewed by Gary Galo

HFN/RR PHONES–01 Headphone Amplifier. HFN/RR Accessories Club, PO Box 200, Bedford, MK40 1YH, UK, +44 (0)1234 741 152. Available from Old Colony Sound Lab, 1-888-924-9465 or www.audioXpress.com. Price: $399 (batteries and charger not included).

The PHONES–01 Headphone Amplifier comes to us from the distinguished British audio designer Ben Duncan. Most of Duncan's numerous writings have appeared in the respected British periodical *Hi-Fi News & Record Review*. His article on the PHONES–01 kit, which is being marketed by the HFN/RR Accessories Club, appeared in the May 1997 issue of the magazine. The kit is available in the US from Old Colony Sound Lab.

The design of a headphone amplifier poses a unique set of problems, which are often compounded by the myriad of load impedances found in the headphone world. Most audio power amplifiers are capable of driving headphones, but this is usually overkill. If a high-impedance dynamic headphone is driven from an amplifier's loudspeaker terminals, the output levels are usually too high, requiring some type of resistive output attenuation.

Many power amplifiers also have noise levels too high for headphone listening. Preamplifier line stages often have output impedances too high for driving headphones. Manufacturers who incorporate dedicated headphone outputs on their products often throw in a cheap 4556 dual op amp, or other low-performance device, for this task, knowing that most users aren't too fussy about the sound quality of the headphone jack.

Serious headphone enthusiasts normally require a special, dedicated amplifier designed specifically for this purpose. There are a number of high-performance headphone amplifiers on the market, but most of the really good ones are very expensive. The PHONES–01 is an affordable amplifier designed to offer performance comparable to "units costing five to ten times as much," according to the manufacturer's literature.

Circuit Details

The basic circuit is shown in *Fig. 1*. The headphone amp is an IC-based design using Analog Devices' SSM 2017 self-contained audio preamplifier for voltage gain and a pair of their BUF04 IC buffers for current amplification. Both chips were designed by Derek Bowers, according to the manual.

The SSM 2017 features a 1MHz bandwidth, 17V/µs slew rate, an extremely low 1.5dB noise figure, and less than 0.01% THD over the full audio bandwidth. Unlike conventional op amps, the SSM 2017 requires only a single external gain set resistor. The 4k75 value yields a voltage gain of 3.2, but you can adjust this to suit your requirements.

The SSM 2017 also includes a fully-floating, true differential input, which Duncan has used to advantage in the PHONES–01. Fully balanced sources are connected in the conventional fashion, with the left and right channels sharing the common ground of the 5-pin XLR input connector on the rear of the PHONES–01. Unbalanced sources can be connected between the + input and ground, but this will not yield the best noise performance and RF rejection.

Duncan recommends using a balanced, two-conductor shielded cable, with the unbalanced signal connected across the + and – inputs. The shield can be grounded at the PHONES–01 input connector and left floating on the other end.

The kit comes with a very high-quality balanced interconnect with silver-plated, oxygen-free copper conductors and Teflon insulation (*Photo 1*). Enough

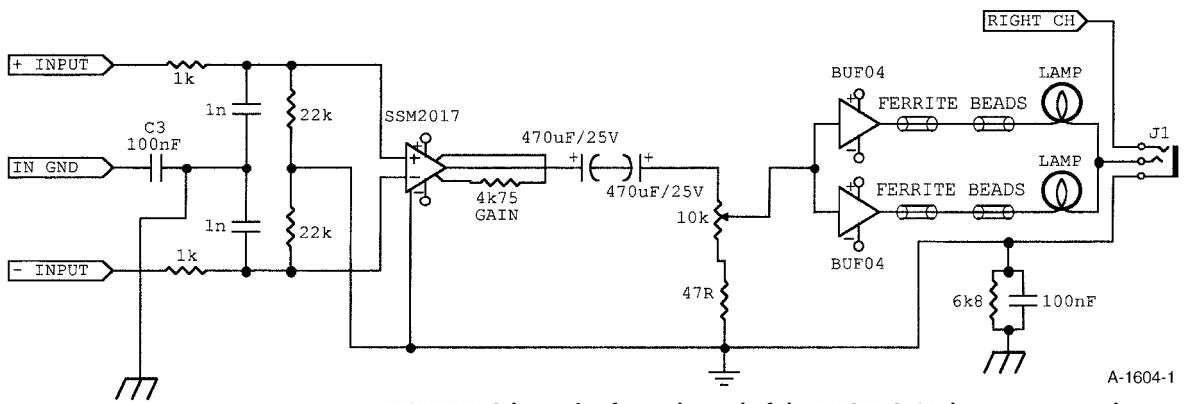

FIGURE 1: Schematic of one channel of the PHONES–01, less power supply connections and local bypassing. An SSM 2017 provides the voltage gain, with a pair of paralleled BUF04 buffer amplifiers supplying enough current to drive medium- to high-impedance headphones.

PHOTO 1: The PHONES–01 kit unpacked. The batteries and charger are not included with the kit—you must purchase them separately.

cable is supplied to make a 1m pair. For longer interconnect runs, DH Labs' BL–1 cable would be ideal. The kit also includes a 5-pin XLR plug for connection to the PHONES–01, but you must supply the connectors for the other end of the interconnect cable.

Output Stage

The output of the SSM 2017 is capacitor-coupled to a Bourns dual 10k conductive plastic volume pot and the BUF04 current amplifiers. This is a change from the originally published design, in which the volume pot was part of the gain-adjustment resistance on the SSM 2017. The new scheme offers even lower noise under operating conditions, since the volume pot attenuates whatever residual noise may be produced by the 2017.

Duncan chose Elna Starget electrolytic capacitors for this purpose, using a pair of 470µF in series, back-to-back, to make a nonpolarized C_{EQ} of 235µF. Duncan notes that the Starget capacitors are of a much higher audio quality than normal electrolytics, so he recommends listening before jumping to conclusions.

If the output offset of the SSM 2017 preamps is less than 50mV, you can bypass the coupling capacitors. If it is much greater than 50mV, you will hear a click when you plug in your headset. Worse yet, high levels of DC offset will displace the headphone diaphragm, which may cause it to operate in a nonlinear fashion.

If your SSM 2017 chips measure higher than 50mV, you could select a few extras for purchase. My review sample measured 33mV in the left channel, but 71mV in the right.

The BUF04 is a high-speed IC buffer featuring a slew rate of 3000V/µs and a bandwidth of 110MHz. The device also has an extremely low offset voltage of <1mV and a very low noise spec of <4nV√Hz. Although the BUF04 is pin compatible with Analog Devices' older BUF03, the BUF04 is a closed-loop, current feedback design. The BUF04 is an all-bipolar chip, manufactured using Analog Devices' Complementary Bipolar (CB) process; the open-loop BUF03 has a FET input.

Design Features

Duncan has used two BUF04s in parallel to double the output current capability, a technique suggested in the data sheet for this device (you can download data sheets for the ICs used in the PHONES–01 from the Analog Devices web site, www.analog.com). Ferrite beads in each output line provide RFI suppression, and the lamps protect the BUF04s from short circuits or very low impedance loads. The BUF04 has no internal short-circuit protection. When two BUF04 devices are connected in parallel, it is imperative that the outputs are never connected together directly or shorted to ground.

Duncan has met this requirement by placing an incandescent lamp in series with the output of each BUF04. In the event of a short to ground or low-impedance load, under high current condi-

tions, the lamps will heat up (and light up), raising the filament resistance, which will protect the output stages of the buffers. The resistance of the lamps is normally very low, but enough to ensure that the outputs track closely, dividing the current to the load equally between the two devices. The ferrite beads in series with the lamps prevent RF oscillation.

Duncan has designed a simple but elegant solution to the problem of charging and power switching. It is important that the charger not be connected to batteries when the unit is in use. If it is, all of the noise and grunge generated by the charger will seriously affect the sonic performance. The charger is normally a switching type, which compounds the noise problem.

The PHONES–01 is designed to be either in the charge mode or the power-on mode—you can't listen while charging. When the power switch is off, it is actually in the "charging" position, with the switch connecting the two 12V batteries in parallel, routed to the charger connector on the rear panel. A diode is placed in series with each of the batteries to protect them from accidentally shorting the charger input connector. The diodes also prevent one battery from "charging" the other if the two have been discharged to different voltages.

The middle position of the three-position power switch is actually a standby mode, in which the batteries are connected in series, with the + and –12V routed to the circuitry through a pair of 47Ω, 0.5W resistors. This provides a "soft start" for the amplifier, with the resistors limiting current through the switch contacts. In the fully-clockwise position the resistors are bypassed, giving the circuitry a low-impedance path to the battery power supply. Since you must always "pass through" the current-limiting position when you turn the amp on, the switch contacts should never arc, which will greatly extend the life of the switch.

Supplying Power

Two 12V lead-acid batteries are needed to power the PHONES–01, but they are not supplied with the kit; neither is the charger—you are expected to purchase them separately. Duncan recommends the Yuasa NP2.1–12. A pair of these, plus a charger manufactured by Automated Systems Ltd., are available directly from the HFN/RR Accessories Club for £70 UK, or roughly $117 US (these were supplied with my review sample).

Information can be found on the British Audio web site accessible at either www.hi-fi-accessories-club.mcmail.com or www.britishaudio.co.uk. This may be the easiest way for European builders to acquire the batteries and charger. The price is certainly fair in US dollars, but shipping to the US will drive the price considerably higher.

I have had no luck locating the Yuasa NP2.1–12 batteries in any of the standard US catalogs, but an equivalent isn't difficult to find. The Yuasa is rated at 2.1Ah (ampere-hours) and measures 7″ × 2 ⅜″ × 1 5⁄16″. The Automated Systems charger is a regulated, switching type rated at 300mA continuous.

Radio Shack now carries a line of lead-acid batteries, new in the 2000 catalog. Catalog number RSU 10457257 is rated at 2.2Ah and has physical dimensions identical to the Yuasa. These are special-order items, drop-shipped to your home address. Cost is $22.99 each. Strangely, Radio Shack doesn't carry any lead-acid battery chargers (their entry into the lead-acid battery market doesn't seem to have been planned very well).

Digi-Key (1-800-344-4539) carries the Panasonic LC–R122R2PU (part no. P171–ND), with physical dimensions also nearly identical to NP2.1–12. This also has a capacity of 2.2Ah and should fit into the PHONES–01 case without difficulty. Digi-Key also carries the Patco InteliTender line of chargers. The 12V model 150 (part no. PATC–04–ND) is rated at 750mA and costs $69.93. The regulated InteliTender chargers monitor the battery voltage and supply only the amount of current needed to maintain the ideal charge.

The connector supplied with the Patco charger is not correct for the PHONES–01, so it's back to Radio Shack for a 5.5mm O.D., 2.1mm I.D. power connector (cat. no. 274–1569). Be sure to make the center contact positive when you attach the connector to the cable on the charger!

Assembly

The PHONES–01 kit took me about 10 hours to assemble. All of the amplification circuitry and the volume pot are housed on the small PC board (*Photo 2*). Connections to and from the PC board consist of input and output wiring, plus the power connections from the rotary power/charging switch. The PHONES–01 is a relatively simple kit well-suited to the novice builder. The assembly manual is generally well-written and includes a copy of the original *HFN&RR* article.

A few points require comment or clarification. The British term "links" simply means "jumpers" in the US. The manual suggests cutting the leads from the six Elna Starget electrolytic capacitors to a length of 3mm, using the discarded wire for the jumpers. This is an excellent idea, since Elna uses tinned, oxygen-free, high-conductivity copper for the capacitor leads. Unfortunately, my capacitor leads were already cut to length, so I used Holco resistor leads for the jumpers, as the manual suggests if you run short.

Connections to the PC board are made to "Vero" pins, which you install on the board. The manual says that the pins will fit easily in the PC board up to their shoulder. Mine didn't. The holes in my PC board were too small for the pins, so I enlarged them with a #50 drill.

A red plastic insulator sheet is supplied for placement under the PC board. This prevents accidental connections between the bottom of the board and the chassis. The manual fails to note that you need to cut the four corners of the plastic sheet to clear the PC board mounting stubs on the chassis.

The most serious problem with my kit was that the power/charging rotary switch was the wrong type. The correct switch is 4-pole, 3-position, but the one supplied with my kit was 3-pole, 6-position. Fortunately, I discovered this before I did any of the wiring to the switch. Undoing all of it would have been a pain, and would also have made quite a mess of the wiring.

I used an "extra" from another project, a physically and electrically identical switch made by C&K, #A40315RNZQ (Newark Electronics stock #81F1018). It is imperative that this switch be a non-shorting type. Contacts of the C&K are silver-plated and rated at 350mA/125V DC.

I informed Mr. Duncan of the problem, so kits shipping by the time you read this should have the correct part. The tip-off is that the correct switch has four contacts in the center—the wrong one has only three. If yours is incorrect, contact the vendor for a replacement. Finally, the wiring diagram shows the channels of the output jack reversed. The industry standard for stereo ¼″ headphone jacks is left channel to the tip, and right to the ring.

The PHONES–01 includes a heavy, robust aluminum case. The only operational annoyance concerns the knobs: there are no marks on the supplied knobs, so you have no idea where volume control and power switch are set. I

placed a drop of black modeling enamel on each knob (*Photo 3*).

Measurements

I ran basic harmonic distortion and SMPTE intermodulation distortion measurements on my Sound Technology 1700B analyzer. I measured THD with an input sine wave of 1V RMS and the PHONES–01 volume control set for 1V out. At 1kHz, THD with a 150Ω load measured 0.0038% in the left channel and 0.0034% in the right. Lowering the load resistance to 100Ω barely made any difference—0.0039% left and 0.0035% right. With either load the distortion waveform was dominated by low-order harmonics and noise.

At 10kHz, the left and right channels measured 0.0045% and 0.0043%, respectively, into 150Ω. Again, lowering the load resistance to 100Ω made virtually no difference—0.0046% left and 0.0044% right. The distortion waveform was dominated by low-order harmonics and noise. With input and output levels lowered to 0.5V, the THD levels were similar, but dominated by noise.

Duncan notes that the THD+N is <0.01% at all gains below clipping, and below 10kHz, with a 150Ω load. My measurements essentially confirm this. He also notes that at normal listening levels the THD+N falls to <0.001%. I don't dispute this, either. The output levels I used for my measurements are far higher than those likely to be encountered listening to program material. Even 0.5V signals will produce dangerously high levels with most headphones.

I determined that the low-order distortion products are generated primarily by the SSM 2017. A number of high-performance IC op amps yield better performance. Walt Jung's AD744/AD811 buffered line stage, discussed in Part 2 of my Pooge 5 article (*TAA* 3/92), shows no sign of any harmonic content on the Sound Technology analyzer—the distortion measurement is entirely noise. The SSM 2017 is easier to implement, however, especially if you desire balanced inputs.

SMPTE IM distortion, with input and output levels set to 1V, measured 0.002% into 150Ω and 0.0044% into 100Ω. The left and right channels were identical. Lowering the input and output levels to 0.5V yielded virtually the same results. Frequency-response measurements showed the –3dB point for the PHONES–01 to be 95kHz. The unit is only 0.25dB down at 20Hz; the –3dB point is well below 1Hz.

Impedances and Coupling

The PHONES–01 was designed to drive headphones with an impedance of 150Ω or higher, which includes many of the AKG and Beyer models and a few Sennheisers, but rules out most others. A look at the latest *Audio* Annual Equipment Directory (Oct. 1999 issue) shows the vast majority of dynamic headsets to be less than 100Ω, with dozens ranging between 16 and 60Ω. My reference dynamic headphones are Grado HP–2s, which have an impedance of 40Ω. The obvious solution is to replace the protection lamps with enough series resistance to keep the load at 150Ω.

As my distortion measurements show, there is virtually no difference in THD levels when the load impedance is dropped from 150Ω to 100Ω. I opted to replace the lamps with 120Ω Holco H2 resistors, which yields an effective output resistance of 60Ω, since the output current is shared by the two BUF04 buffers. With the 40Ω impedance of the Grados, the amplifier now sees a 100Ω load. The Analog Devices data sheet for the BUF04 shows a similar implementa-

tion—100Ω series output resistors driving a 50Ω load, so a 100Ω load is certainly within the limits recommended by the IC manufacturer.

In my correspondence with Ben Duncan, he noted that some users have driven Grado headphones directly, using only the series lamps and no added resistance. I tried this and found that the amplifier still performed extremely well—it is only very slightly cleaner on transients with the added series resistance. The manual notes that currents in excess of what the paralleled BUF04 devices can deliver with low distortion will cause the lamps to light on peaks.

As an experiment, I connected a CD player to the PHONES–01 on my test bench, plugged in a set of Grados and cranked the volume high enough to make the headphones clearly audible at a distance of several feet from my ears (I did not put them on!). Even with the room lighting turned off, I could not see any signs of illumination from the lamps in the PHONES–01. No one would ever approach these volume levels in normal listening.

It is important to remember that the load impedance and the output voltage determine the output currents required to drive a given pair of headphones. Duncan is wisely conservative in cautioning against load impedances below 150Ω. But, at normal (and safe) volume levels, the PHONES–01 seems quite content driving lower-impedance loads. If you plan to use Grado headphones, I recommend experimentation. Try them with the lamps and then replace the lamps with 120Ω resistors. The "Vero" pins used in the PC board make removing the lamps and installing resistors simple—you don't need to remove the PC board to do this.

If you observe an improvement with the resistors, you may be hearing the removal of the contact points between the lamps and their sockets. The threaded portion is a brass-to-brass contact, and the lamp tip is basically a solder blob pressed against brass at the base of the socket. Neither of these connections is ideal from an audiophile standpoint. I recommend putting Caig DeoxIT contact cleaner on the lamp contacts.

The Sound

If you are used to the "throw-away" headphone outputs supplied with most commercial equipment, the performance of the PHONES–01 will be a revelation. The most immediately striking characteristic of the PHONES–01 is its punchy dynamics and robust bass. The low-impedance supply provided by the battery-powering, combined with the high current capability of the paralleled BUF04s, certainly pays off in this regard.

Tonally, the amp leans toward warmth in the upper bass/lower midrange, particularly with my Grado HP–2s, which tend to be a bit soft in the treble. And the PHONES–01 did not color their basic characteristics.

The PHONES–01 reproduces a very spacious soundstage, with excellent ambience retrieval. By comparison, just about any headphone amp included with CD players and preamps will sound narrow and dry. If you do an A–B comparison with the PHONES–01 and almost any headphone amp included "for free" with your equipment, the soundstage becomes so narrow with these cheap amplifiers that they almost sound like mono in comparison to the incredibly spacious PHONES–01.

Although no headphones or amplifier can give you the sense of front-to-back localization that you get with loudspeakers, the PHONES–01 does give you an uncanny sense of distance between you and the performers in the back rows of the stage. It also excelled in reproducing the unique acoustical characteristics of the halls in which my various reference recordings were made.

The PHONES–01 is excellent in its reproduction of inner detail and articulation and maintains excellent clarity in heavily-scored orchestral passages. The PHONES–01 is completely non-fatiguing in its sonic presentation and will provide hours of musically satisfying listening. Thanks to the battery-powering and the low noise of the Analog Devices chips, the PHONES–01 gives your music a dead-silent background. If you hear any noise, it's on the recording.

I decided to try removing the coupling capacitors and replacing them with jumpers. I had several samples of the SSM 2017 on hand, so I selected a couple for less than 50mV offset in each channel. I believe the capacitors contribute to a slight veiling of the sound—if you own a

PHOTO 3: Front view of the PHONES–01. I painted the black dots on the knobs, since they have no markings. The ¼" jack is a high-quality, Swiss-made Neutrik connector, as is the 5-pin XLR input connector on the rear panel.

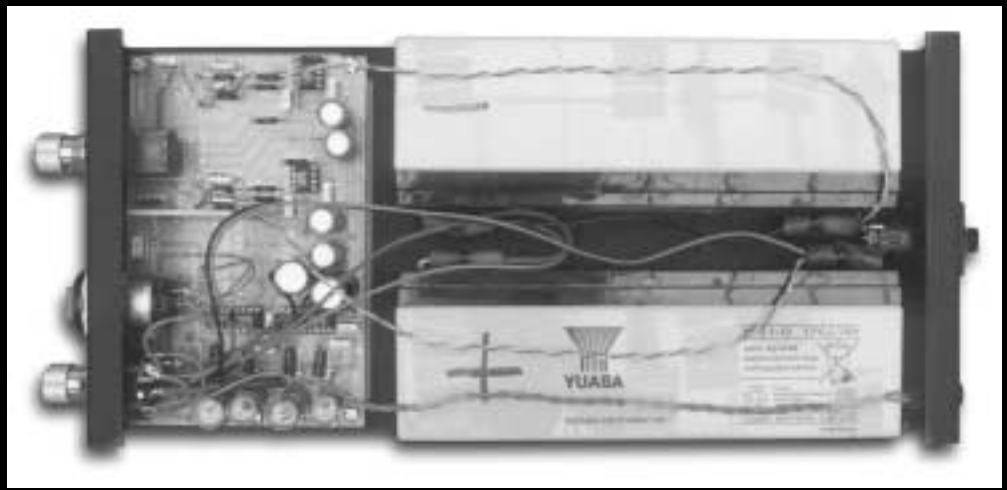

PHOTO 2: Inside view of the PHONES–01. All circuitry is contained on the single PC board. The batteries and robust metal case account for most of the weight. The lamps can be easily replaced with resistors for driving low-impedance loads, such as in the Grado headphones.

high-end pair of headphones, you are better off without the capacitors.

If you need to purchase extra SSM 2017 chips, try Newark Electronics (www.newark.com). The current price for the "P" version is around $3.25 each. At this price, the capacitor removal is a worthwhile and cost-effective improvement. You shouldn't need to buy more than four to get a pair with offsets of less than 50mV. Check your PHONES–01 with a DMM before you buy more chips—if you're really lucky you may already have a pair with sufficiently low offset.

Conclusion

Does the PHONES–01 offer the best possible headphone amplifier performance? Not quite, in my opinion. For comparison, I tried connecting my Grado HP–2s directly to the outputs of my own preamplifier, which uses the Jung AD744/AD811 line stage powered by Jung/Didden regulators (*TAA* 1–4/96).

To do this, I made an adapter using Canare F-10 RCA plugs, two half-meter lengths of DH Labs BL–1 interconnect and a Switchcraft in-line female stereo ¼" phone jack. This yields the finest headphone reproduction I have ever heard. It is noticeably cleaner, more detailed, and even more spacious than the PHONES–01.

In fact, the 744/811 line stage with Jung/Didden regulators reveals the almost pristine character of the Grado headphones to their fullest. This level of performance is a testament to the excellence of Walt Jung's regulator design. The 744/811 line stage powered with these regulators actually beats a battery-powered unit with zero AC line noise!

This must be put into perspective, however. A commercial preamp comparable in performance to my own would cost thousands of dollars. The PHONES–01 will give most commercial headphone amps a run for their money, regardless of cost. Those who do field-recording work will find them an excellent reference tool, and the battery-powering may prove to be a handy feature when you're "on the road."

Even with the cost of the batteries and charger added in, the asking price is extremely fair for this level of performance. It is an enjoyable kit to build, as well. If you are a serious headphone user requiring a high-quality amplifier at a reasonable price, I highly recommend the PHONES–01.

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Ben Duncan responds:

Gary Galo's review is thorough indeed, but two special features of the SSM 2017 are worthy of expansion. First, due to the use of current feedback as well as ordinary voltage feedback, the 1MHz bandwidth persists as you increase the gain. Therefore, you can alter the gain of PHONES–01 with less expectation of sonic changes due to both alterations in loop gain, and also RF linearity—in the face of low RF noise.

Second, the 2017's true balanced input is superior to almost all conventional, active balanced inputs, working almost like a perfect transformer. While accepting the reviewer's statement that unbalanced sources will not give as good results (vis à vis external noise rejection) as balanced sources, I must say that as the choice of audio-grade gear or even DIY designs with balanced outputs is so small, what surely counts is the ability of PHONES–01's input to nonetheless get the best out of unbalanced sources. PHONES–01 is also one of very few audio products having input wiring that ensures RF rejection in accordance with enhanced practices[1,2]. This robust proofing against RF is becoming increasingly essential for many listeners, else sonic quality is dictated by the environment, over equipment finesse.

The battery is a size that's been spec'd into alarm and other internationally manufactured consumer-electronic mains back-up systems for nearly 20 years, so it should be about as "world industry standard" as you can get, but maybe not so much in the US, I confess. As for chargers, if you follow the information available from the battery makers and also given clearly in the builder's manual and original article[3] and update[4], you'll see all that's needed is a stable, below 1A supply of just below 14V—that can be set using an accurate 3.5 or better DMM—to a specific voltage within about 200mV (0.2V).

Regarding the charging inlet switching, I am glad my design thoroughness has been appreciated. I must add that it was designed to isolate the circuitry 100% from "galvanic" connection, hence common-mode mains noise while listening, which, as already mentioned in these pages[5], can affect even the best-smoothed, lowest-noise supplies, and which will have most benefit in today's increasingly noisy, urban, and even suburban neighborhoods.

The "Vero" pins are made to "swage" fit. The way I fit them is to squeeze the pin into the hole with pliers, up to their collar. Solder is then introduced and the iron tip is then applied and used to press the pin home. Drilling is fine but needs to be just right, within 5 thou (0.005″), else the pin can wiggle when soldering, readily giving a dry joint.

The quality of any PHONES–01 kit as delivered is in the hands of HFN/RR Accessories Club (alias Moth Marketing). A corrected copy of the builder's guide, with all the reviewer's points taken up, has been passed by myself to them. The sending of the wrong switch is one sort of mistake that even Moth Marketing's ISO–9001/2 registered supplier companies can make.

Any error in a kit is not excusable, but to put matters in perspective, even in a simple kit like this, there are maybe 10,000 possibilities for

error. What counts is that if any builder is unlucky in this way, prompt help is on hand anywhere you live, by e-mailing Moth, who would see the correct part is sent on to you ASAP. It is best to report any shortages or defects even if you do fix the problem yourself, as all suppliers need feedback.

PHONES-01 was measured during design and characterized using my personal Audio Precision Inc. *System One* test set, which I believe exceeds the resolution of the Sound Technology 1700B by some margin and has taken its place as the world's *de facto* standard for %THD+N testing. 2017 and BUF-04 performance is pretty consistent in the population, but to be sure, I add a margin, so the specs will tend to seem a shade pessimistic. Prior to designing PHONES-01, I had also examined the spectral content of the ICs used among other modern parts, using the AP System One's Dual Domain (DSP-based) test facility to examine harmonic spectra up to 140dB down—below the noise that hides details with all conventional %THD analyzers. This work[6]—which is the sequel to earlier work also seen[7] in these pages—has so far been published only in the professional press. The results presented here should cast light on my choice of ICs.

As it was Walt Jung's *IC Op-Amp Cookbook* that more than most set me on the road to success with electronics since I encountered it a quarter of a century ago, I could hardly be unhappy that my work is compared as being second to his own. Still, something may have been missed. Very often, music reproduction finesse is destroyed by hums, buzzes, and other environmental noise coupled when signal sources are connected. The SSM 2017's true balancing protects greatly against this. Like myself, the reviewer is perhaps lucky to live somewhere that's electrically quiet. For many others, if Walt's fine circuitry is to work at its best, it would take about three of the AD744/811 stages to create an SSM 2017 type balanced topology. This would seem to be a truer comparison.

Also, a distortion you can't measure (even with the AP test set) is not necessarily a distortion you cannot hear. The net distortion of PHONES-01 is musically highly benign as well as lower than most. I argue that this is better than a valve (tube) amplifier with its gross (albeit euphonious) distortion, but also better to sensitive enough ears than a near zero distortion stage (such as Walt's or any stage using, say, the AD797), which will still have some distortion hidden in the noise, that will also likely not be euphonious[8]. In the UK, this general principle has been borne out by the listening experiences of colleagues.

Concerning headphone impedances, my "Black Box" column[9] in the month preceding the original DIY design considered this issue. This piece is a vital appendix. A keynote of amplifier design[10] also covered recently by another British researcher in these pages[11] is that however much mastery you have of circuitry, power amplifier distortion is ultimately proportioned in the first degree to the lowness of the impedance being driven. This is one reason why the established European headphone makers mentioned had wisely established above 100Ω as the standard for high fidelity.

Although I should respect the engineering choices of a maker of fine repute such as Grado, it would seem in general that the rest of the world's headphone makers would appear to be ignorant about the demands placed on the electronics required to drive their ill-considered impedances! They are likely more concerned with the fact that lower impedances will play louder when plugged into any given headphone socket—and likely fool the purchaser into thinking the efficiency or sensitivity is higher! There's more on this in ref [9].

Finally, the review begins by saying most of my writing has been in *Hi-Fi News*. Having had over 100 articles/installments/column pieces in that magazine, I can see where the impression comes from, but my total of over 600 audio-related articles has been spread across about 20 UK and US publications. For the record, I have enjoyed reading and learnt much from *TAA/AE* since I first became a reader in 1980. ■