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METER READINGS

I like the fact that author Todd Sharp appreciates the utility of older high-quality audio measurement equipment ("A First Rate Audio Test Instrument, Part 1," June '06, p. 26). Readers should be aware of one limitation of the 403B. Like all the HP 400 series AC voltmeters, the 403B is not a true RMS reading meter despite the RMS VOLTS on the meter face. It responds to the average of the AC input waveform, but is calibrated to the RMS value of a pure sine wave. This could cause errors in measuring frequency response if the amplifier under test introduces significant distortion of the test signal.

The HP 3400A is a true RMS reading voltmeter with the same width and height as the HP 402C and 403B, but unfortunately it is too deep (279mm vs. 203mm) for the 3550B chassis.

Mr. Sharp has made valuable modifications to the units and I look forward to Part 2 of his project.

Chuck Hansen
Ocean, N.J.

Todd Sharp responds:

Thanks to Mr. Hansen for pointing this out. Indeed, the HP403b may indicate some degree of error while measuring waveforms with harmonic content. I have included an error chart from HP literature for consideration (**Table 1**).

Though I do appreciate the older analog gear (love those giant meters and knobs), I have personally found the HP 3400A to be considerably more difficult to repair and calibrate. Limitations notwithstanding, I stand by the 403b as a dandy little workhorse for mere pennies on the dollar! I also submit that its average responding scale may be relied on with a high degree of accuracy while viewing pure sine waves—which is most often the standard for bench testing basic amplifier performance.

Part 2 of this article (July '06) reveals that this modified set, which also features a convenient interface for oscilloscope and loudspeaker monitoring, provides the basic blocks for a compact yet affordable quality audio test bench that could well serve the neophyte, while offering portable test utility for the professional. I suspect that many readers would augment something like this with additional devices for more specialized purposes such as a good digital meter with a true RMS function.

After reading Mr. Hansen's letter, I did make some comparisons between *true* and *average* responding meters during the course of everyday repair work here at our shop. A few such comparisons follow:

While observing a sine wave just clipping a push-pull tube amp at 50W (THD measuring 5.4%), I noted that the modified 403b indicated identical amplitude as did a Fluke 8050A True RMS digital meter. The same test on a Hafler P1500 at 105W (1.2% THD) and frequency response tests on a Crown CE 2000 again produced identical readings.

Table 1. Effect of Harmonics on Model 403B Voltage Measurements.

Input Voltage Characteristics	True RMS Value	Value Indicated by 403B
Fundamental = 100	100	100
Fundamental + 10% 2nd harmonic	100.5	100
Fundamental + 20% 2nd harmonic	102	100 - 102
Funcamental + 50% 2nd harmonic	112	100 - 110
Fundamental + 10% 3rd harmonic	100.5	96 - 104
Fundamental + 20% 3rd harmonic	102	94 - 108
Fundamental + 50% 3rd harmonic	112	90 - 116

In regard to part 1 of Todd Sharp's test instrument article, most astute readers will have noticed that in Fig. 2 the symbol for transistor Q7 should be PNP, the arrow should point inwards, as it is the same transistor Q7 of Fig. 1.

Novice readers will have more problems with the two missing off-sheet connector symbols. One connects Q7's emitter from Fig. 2 to the circuit at the left of Q7's emitter in Fig. 1. The other connects the node comprised of resistors R41 and R2 along with C2's negative terminal from Fig. 2 to the node made of R41, C21's negative terminal and CR5's and CR7's anode terminals of Fig. 1.

This article, and others such as "Noise Meter Amp" (Jan. '05) and "Pooge for eBay Test Gear" (May '06)—both by Charles Hansen—should be of interest to all audio amateurs who want to improve their home laboratory with professional-quality test equipment. Professional solid-state test equipment built in the 1960s, 70s, and 80s is very useful to the hobbyist and amateur alike. Companies such as Hewlett-Packard (now Agilent), Tektronix, Fluke, General Radio (now Gen-Rad), Wavetek, and others sold many interesting instruments.

Most equipment designed for the professional market is now available for a fraction of their original price, sometimes even for free. They are mostly made up from discrete components (e.g., not surface-mounted) and use very few custom components, except for the cabinet, power transformer, switches, and analog meter movement. Most spare parts are commonly available. Service manuals are also available, sometimes for free, at many websites such as BAMA http://bama.sbc.edu/. To find such test equipment look at yard sales, HAMfests, surplus and second-hand stores, pawn shops, used test equipment stores, and at online auction sites.

The problems you may encounter: cleaning the outsides and insides, troubleshooting and repair, paying more for the manual than what you paid for the instrument, looking for parts made of unobtainium (a fake element name to mean that some parts are no longer available), buying more than one unit so you can have spare parts, and generally learning and having fun with electronics.

One instrument of interest is the Hewlett-Packard 4328A Milliohmmeter, which was designed in the late 1960s. This analog instrument offers AC resistance measurement, 1mΩ to 100Ω full-scale in 11 ranges, low test signal 20mV peak across the sample, typical 200µV peak, 1kHz test frequency, and the possibility of measuring all this with 150V DC across the sample to be tested. Accuracy is 2% even when the reactance of the sample is twice the full scale range reading, so you can use it to measure capacitor internal resistance (ESR) quite easily. It was available with option 001, a rechargeable battery. This model option will benefit from Mr. Sharp's modifications to replace the batteries. Armed with a capacitance meter and this milliohmmeter, you can track down old dried-up aluminum electrolytic capacitors very quickly.

Daniel Dufresne
Saint-Laurent, Québec

Todd Sharp responds:
I thank Mr. Dufresne for catching the error in Fig. 2, where Q7 is shown as a NPN transistor. It should be a PNP. My apologies for not catching this in proofreading.

Regarding the other questions raised: Readers may notice the vertical dotted line in Fig. 2 which depicts "existing circuit" and "new circuit." The emitter of Q7 is never disconnected, although I can see where you might draw that conclusion based on the way Fig. 2 is presented. The text of the article explains this along with the other connection in question.

I am pleased that you found the article of interest.

I enjoyed Todd Sharp's article on the HP 203c renovation project. I really think a person could get the new NiCads specially made up at Battery Plus instead of putting capacitors and zeners in their place and changing the circuits.

I need help on a JL Audio 1000/1 bass amp. The problem is that the green power LED lights (normal), and the yellow LED lights (low ohm) with the speaker disconnected (on purpose in case there was a voltage, no speaker damage would occur). There are no shorts that I can find in the 31 N-channel power MOSFETs or the four dual rectifiers that look like TO-220 transistors, and no shorts between the speaker terminals, which measure about 2MΩ.

Please tell me this information if possible. This amp is Class D fed with pulse width modulation. I don't know what else to test.

Tim Rasch
tim5310@yahoo.com

Todd Sharp responds:
You make a good point in your letter. I was not aware that you could have NiCads made up in custom configurations. In either case, I would consider the cost vs. application carefully before making the investment. There are advantages and disadvantages to rechargeable battery operation. As the article points out, the NiCad cells are often the problem area in resurrecting not only the 403b and 204c, but a wide variety of test gear from this era. Such gear is otherwise of top quality and readily obtainable at bargain prices.

I am no expert on battery technology, but I will share my limited experience on the topic since you have raised it. The advantages of battery-operated test equipment are mainly twofold: 1) AC line isolation and freedom from ground loops, which can be especially troublesome at very low measurement levels, 2) remote operation without having to plug in to a power source, provided the cells are adequately charged.

The disadvantages as I have experienced them are: NiCad cells have a limited charge cycle life and are susceptible to memory effect. If you do not discharge them completely before recharging them, they tend to yield a much shorter service life. Therefore, you will be buying more batteries at some point in order to keep your stuff operational.

There are a few methods of resurrecting NiCads such as "zapping" with high voltage pulses, but this is not possible with 6V types. As I understand it, all batteries are actually 1.2V cells. The 6V types required in this set are made up of five 1.2 cells stacked in series and then sealed as a single 6V cell. Each HP piece in my article requires four 6V cells. Personally, I have rare cause to use the "battery power" function. I just leave them plugged in, which means I would be buying new custom made NiCads more often than if I allowed the cells to discharge fully.

You also need to be aware that these cells are required to be in good shape even when operating from the AC line, because they are in fact utilized as filters for the rectified AC line supply. As if that isn't enough, if one of the cells (in the string of 20) is going bad (which is not uncommon), the resulting leakage causes further power supply trouble.

So, replacing these buggers with a few filter caps and a few diodes may make more sense than you would initially imagine. There are newer technology NIMH cells available which seem to work much better than NiCads. Perhaps someone with deeper understanding of current rechargeable battery technology could pick this topic up and shed more light for all of us.

Thank you for your comment. Glad you found the project of interest.

CORRECTION

Readers should note that in part 2 of my article (July '06), J2 (speaker) is drawn incorrectly in Fig. 2 (p. 42) as a shorting type jack. It should be a two-terminal mono jack without shorting contacts. It is listed correctly in the parts list as a Switchcraft #11.

There are also two typos in Fig 2: SW3 position "X11" should say "X1" and the two + binding posts should be indicated as BP3 and BP4.

Todd Sharp
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NOISE AND DISTORTION

The Audio Amateur has published noise values for some operational amplifiers—in 1/1979 by Michael Lampyon and Don Zukauckas as well as in my 2/1994 article. These noise values are not frequency-weighted.

Due to the Fletcher-Munson effect, the human ear is most sensitive to noise in the frequency range 900Hz-7kHz. Noise from operational amplifiers should be filtered to match the Fletcher-Munson curve. An "A"-weighting filter was published by Phillipe Trolliet in *TAA* 3/1981.

If you use the operational amplifier in an RIAA amplifier, then you must sum the effects on the noise of the RIAA filter and the weighting filter. I use a very simple filter for noise measurements (**Fig. 1**).

The distortion values for some of the operational amplifiers are taken from my article in *TAA* 2/94. Filter

FREQUENCY	A-FILTER	A-FILTER + RIAA	ACTUAL FILTER
20Hz	-50dB	-31dB	-28.5dB
50Hz	-30dB	-13dB	-21dB
100Hz	-20dB	-7dB	-16dB
500Hz	-3.5dB	-0.5dB	-3dB
1kHz	0dB	0dB	-2.5dB
5kHz	0dB	-8dB	-10dB
10kHz	-3dB	-17dB	-20dB
15kHz	-6dB	-23dB	-24dB

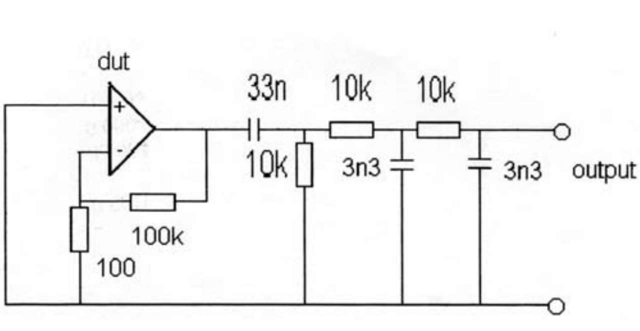
OPERATIONAL AMPLIFIERS

SINGLE	NOISE MV	DISTORTION %
OP 07	140	0.53
OP27	-	0.0016
OPA27	80	-
OP37	-	<0.0003
TL061	860	0.27
TL071	433	0.0008
TL081	490	0.0019
OPA121	155	0.39
OPA134	238	-
OPA137	792	-
OPA177	116	-
LM308	530	0.13
LM318	420	<0.0003
LF351	528	0.0042
LF356	655	0.032
LF357	457	0.0016
OPA602	330	-
OPA603	103	-
OPA606	35	-
AD645	187	-
LM725CN	71	-
741	-	0.78
LT1001	149	-
LT1016	11	-
LT1115	45	<0.0003
TLE2061	952	-
2134	89	0.0003
CA3140	808	0.0045
NE5534	113	-
LM6181	158	-
DUAL		
TL052	480	-
TL062	690	-
TL072	445	0.0010
OP80G	104	-
TL082	445	0.0004
LF353	440	0.0004
LM358	990	0.0004
TIS512	251	-
UA772	490	0.0032
LM833	131	-
1458	920	0.41
2139	103	0.0003
LM2904	635	-
CA3240	785	0.0039
4558	325	0.0078
NE5512	735	0.016
NE5532	185	<0.0003
QUADS		
TL074	515	0.029
TL084	595	0.029
LM324	655	0.33
LF347	610	0.0005
LM348	905	0.44
LM349	1590	0.0026
OP400	135	-
LT1014	460	1.2
MC3403	1010	0.52
NE5514	905	0.018

characteristics are for "A"-filter, "A"-filter + RIAA, and the filter that I used.

Rickard Berglund
Sweden

FIGURE 1: Noise measurements in op-amps.



KEEPING COOL

I read with interest part 2 of Dennis Colin's Mad Katy 250W tube power amp (July '06 *aX*). I see that an "Optional" fan is included. I suggest that the fan is not optional but a necessity. The measurements as given make the centers of the KT88s 3.14″ apart. (I must say further apart than some designs I have seen of late.)

The M-O Valve Co Ltd Bulletin on the GEC KT88s December 1974 states that KT88s should be 4″ apart center to center, and correctly oriented. The reason for this is that with KT88s producing this amount of power the envelope/bulb temperature gets up to about 250° C, which is 2.5 times the boiling point of water. With so much heat concentrated in such a small area, I question the reliability of surrounding components.

I have recently built a 100W per channel tube amp using KT88s with the M-O Valve specs and have put in a fan to do some cooling.

Alan Smith
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Dennis Colin responds:

As the article shows (Table 2, p. 55), at +24° C ambient and no signal (398W AC consumption), the hottest KT88 envelope spot is 195° C (no fan) and 163° C with fan. Calculating for maximum music signal (≈ 500W AC line) and 100° F (38° C) ambient, the KT88 envelope would reach about 225° C (no fan) and 190° C with fan.

This is with the Papst 3412L fan (12V design) operated at 6V. I measured its wind speed as 4.6mph (2.06m/s) and its "A" weighted noise as only 7dB SPL at 3m. Running the fan at 12V produces a wind speed of 10.3mph (4.60m/s) and noise of 24dB SPL at 3m. This would more than double the cooling.

I power the fan from the 6.3V DC supply in the amp. You could also connect it across the ±6.3V supplies for 12.6V operation. The higher noise of 24dB SPL at 3m is just barely audible here in the New Hampshire mountains on a winter night.

I appreciate your letter and agree with you. I always use the fan (on 6.3V). Incidentally, the reason the KT88 maximum envelope temperature is 195° C, not 250°, is that the plate plus screen dissipation is only 28W maximum, with reference to the recommended Genelex rating of 40W.

HIGH-QUALITY AC PLUGS, SOCKETS

A few weeks ago I rewired an auxiliary power supply with audiophile-approved AC wire and a robust 15A plug, replacing one of "lamp cord" quality.

By chance I stumbled across a Marinco plug (marinco.com), the most wonderfully engineered and beautifully made plug I've used. Previous plugs have been the type that look good enough, are reasonably priced, and made in China. I am sure their retailers are making handsome profits on them.

The Marinco plugs and wall outlet sockets are identified as being made in the USA, and in fact cost no more than the imports. I have therefore won on all three fronts—quality American manufacture, competitive pricing, and unmistakable sonic improvements.

Darcy E. Staggs
Orange, Calif.

PHASE INVERTER DESIGN

Robert Bennett's article, "An Improved Split-Load Phase Inverter" (*aX* 7/06), was interesting, but left me puzzled as to his interpretation of circuit action.

I agree that if the input to a phase splitter is truly made between its grid and cathode, then the undesirable features he mentions would be eliminated. That's because such a connection would eliminate the negative feedback inherent in the stage when it's used in the classic configuration (Fig. 1, p. 25 of July issue). Unfortunately, despite his explanation, I don't see how his approach provides that connection in either example he's offered (Figs. 2 and 3, pp. 26 and 27).

A sure-fire way to produce it would be to use transformer coupling into the splitter, with the secondary connected in place of his R12 of Fig. 2. Of course, C7 and C8 would be eliminated, and R5 would be lowered to match R6 to balance the outputs. In this setting, the raw stage (not counting any transformer action) would actually provide some gain (about 8 to either output, or 16 between both outputs with a 6J5), and behave similarly on each output with respect to frequency balance, output impedance, and loading, all as Mr. Bennett suggests.

The transformer coupling in my example truly allows the inverter's input to be "returned" to the top of R5 rather than ground, so that the signal applied from the transformer between the grid and cathode is unaffected by the cathode signal appearing between the top of R5 and ground. In other words, the input signal "floats" on top of the cathode output signal.

In Mr. Bennett's example, however, the signal from the pentode stage is still effectively applied between the inverter's grid and ground, because that is the point the cathodes of both stages reference. On paper it may *look* as though the signal is applied between the inverter's grid and cathode, but I suggest that in reality, it's not.

Consider in his Fig. 2 if you remove C8 for a moment, and reduce R5 to match R6 at 20K. Then, if a 10V signal (ref. ground) is produced at the plate of V1, it means that 92.6% of it is produced across R3, with the remainder across R11 if the B+ line is properly bypassed. Also about 95% of V1's plate signal will appear across R5, because the inverter is now operating in a classic configuration with the cathode output signal applied as NFB against the inverter's input signal.

However, if you now re-install C8, and increase R5 to the listed value of 40K, the circuit action changes, but not as I believe Mr. Bennett suggests. Now, a 10V signal at the plate of V1 will still produce about 95% of that voltage across R5, *but also* across R11, which means only 5% of the 10V drive signal is now appearing across R3, versus nearly 93% before; hence, the bootstrap action.

In this case, the effect of the bootstrap is to practically make R3 dynamically disappear. Mr. Bennett states that such treatment has no effect on the gain of the pentode. I question this as well. The bootstrap has effectively made R3 "appear" as almost 19 times its actual value, which allows the pentode to approach its theoretical maximum gain by operating in a nearly constant-current mode. I believe this is the real benefit of the design. That is, it maximizes the gain of the pentode stage, rather than enhancing the performance of the inverter stage. In fact, I believe the performance of the actual inverter as shown in Figs. 2 or 3 has pretty much the same drawbacks as listed at the beginning of the article, but now with two new concerns.

As shown, any adverse loading on the cathode output will not only have a potentially opposite effect on the plate output as before, but can now also upset the bootstrap connection as well. This could lower the pentode's gain and reduce the effectiveness of any global feedback network in place. Additionally, because R5 works in tandem with R11 to provide a balance with R6, the value of R5 is doubled over that of R6. While this restores AC balance, it also reduces the DC current that the stage can pass (as opposed to that where R5 = R6), which in turn reduces its peak output capabilities. You should also consider this if you're contemplating a change to the bootstrap connection.

Finally, Mr. Bennett's comments on heater bias for a splitter design are well founded, and often neglected. I would also add that the bias supply for the heaters should always be adequately bypassed to ground as a further aid in minimizing noise.

All of that said, the phase splitter is a good circuit, and there is much to commend it for. Most of its limitations can be effectively dealt with, because its well-publicized drawbacks rarely produce the level of problems in reality that it's been debated to have in theory over the last 50+ years. I would appreciate any comments Mr. Bennett might have on this in case I just don't get it—which, of course, is always possible!

David C. Gillespie
Atlanta, Ga.

Robert Bennett responds:

David Gillespie's letter raised some interesting points.

His suggestion of a split-load phase inverter, with input transformer-coupled between grid and cathode, is an intriguing one, which might well have practical merit.

As far as the bootstrap circuit is concerned, you can analyze it in a number of ways, but the analysis requires some care, considering the circuit as a whole, without separating the parts. Surprisingly, the gain and output resistances of this circuit are very similar to Mr. Gillespie's suggested transformer-coupled circuit, provided that the pentode plate resistance is much larger than its load resistance.

The voltage at the 6J5 cathode output is about 90% of the grid voltage. The bootstrap connection increases the effective anode load of the 6SJ7 by a factor of 1/(1-0.9) = 9 roughly.

The 6SJ7 has a plate resistance of about 3MΩ and a transconductance of about 1mA/V under the circuit conditions. The higher effective load increases its gain by about six times, from 230 to 1200. The total gain from input to one output is about 1100.

The split-load phase inverter normally has a very low impedance at the cathode output (roughly 1500Ω for the 6J5) because of the negative feedback from the cathode resistor. The impedance at the anode output is much higher.

The output impedance at the cathode is: (6J5 plate resistance + cathode resistor)/(mu+1) = 1500Ω.

However, in the bootstrap circuit, there is an equal amount of positive feedback increasing the pentode's gain. This largely cancels out the effect of the negative feedback, increasing the cathode output impedance back to a fairly normal value.

The bootstrap increases the effective output impedance of the cathode channel by a factor of about 6, which brings it up to roughly the same level as the output impedance of the anode channel.

With a normal split-load phase inverter, if the cathode output is shorted, the output at the anode increases dramatically, by a factor of about 15 for a 6J5, for example.

With the bootstrap circuit, shorting the cathode output also shorts the bootstrap feedback, reducing the pentode's gain by a factor of about 6, so the output from the triode increases by a factor of only about 2.

Mr. Gillespie considers the effect of a voltage generator applied between pentode anode and earth. This would short out the bootstrap feedback and lead to erroneous conclusions. It would be better to consider the pentode as a current generator in parallel with a very high resistance (the plate resistance of the pentode).

Mr. Gillespie also comments that the maximum output swing of the bootstrap circuit is reduced because of the AC load of the bootstrap. This is correct. This problem could be avoided by direct-coupling the top end of the pentode load resistor to the triode cathode. Mr. Gillespie's final point about having the heater supply well bypassed is particularly important with high impedance circuits such as this one.

I agree that the traditional form of split-load phase inverter works well enough in practice if the amplifier is not overdriven. Perhaps if other circuits had been used for as many years, they would also have been found to have drawbacks. Finally, I would again like to thank Mr. Gillespie for his letter, which has caused me to look again at the references and do some hard (but worthwhile) wrestling with circuit analysis. *aX*