Part 4

REGULATORS FOR HIGH-PERFORMANCE AUDIO:

Real-World Implementations and Sonic Evaluations

By Gary A. Galo
Contributing Editor

In the first three issues of 1995, *TAA* readers were given a wealth of information on state-of-the-art regulators for low-level audio applications. Now that you've seen Walt Jung's circuits (1/95, p. 8), analyzed his measurement data (2/95, p. 20), and built Jan Didden's clean, easy-to-assemble printed circuit board (3/95, p. 20), you're ready to drop a few of these regulators into real-world projects. Perhaps you've been reluctant to build them until a report on how they affect the sound was published. This, and more, is what Part 4 is all about.

Over the past several months I've amassed a great deal of experience building and implementing these regulators using Jan's PC boards. I have installed and evaluated ±14V versions in an extensively modified Adcom GFP-565 preamplifier, along with +5V, –5V, and –15V versions in a Philips DAC960 digital-to-analog converter modified to Pooge 5.5 standards.[1,2] From reading Parts 1–3, you know that these fast, ultra-wideband regulators require careful attention to parts selection and layout in order to perform to their potential.

As Jan's article so aptly illustrates, there are more "components" in a circuit than those shown in the schematic diagram, and much more to these regulators than input, ground, and output. Jan's Fig. 1 shows the other components that exist within a real-world regulator circuit, and even more phantom inductances, capacitances, and resistances can enter the picture once the regulator is installed in a real-world device. With a feature as sophisticated as remote sensing, the assembled boards can't be considered drop-in replacements for the old 7815 and 7915 three-terminal types. Connecting these regulators to real electronic circuits requires considerably more effort—and expertise—on the part of the builder.

Test Gear Necessities

At several points throughout the previous articles, Walt and Jan have mentioned the potential for oscillation of these regulators. With such sophisticated circuitry, we can no longer rely only on a digital voltmeter for regulator testing (though we certainly *do* need one). A wideband oscilloscope, 20MHz minimum, is an absolute must for verifying their proper operation. I know many of you will be tempted to build and install these devices without a scope, *but you must avoid this temptation at all costs.*

Jan's excellent PC board is extremely simple to assemble. Thanks to a clean layout and clear instructions, it resembles a "One Evening" novice Heathkit project, but its simplicity is incredibly deceiving. Implementing these regulators in an overall system design is no less than an advanced project. Whether you use the regulators as part of a new design or modify existing equipment, there's no substitute for proper test equipment.

A few of my experiences may help emphasize this point. In issue 2/86 I reviewed Phoenix Systems' P-94-SR Parametric Equalizer Kit.[3] This was a Heathkit-style project, in which builders assembled the factory-made printed circuit boards and mounted everything in factory-supplied cases. Since this was a finished kit design, you would expect it to operate perfectly when it was completed. Mine didn't.

Ever since I began working with fast, wideband op amps in the late 1970s, I have always checked power supply rails for oscillations. I found a problem when I checked these. Far from sophisticated, wideband regulators, this equalizer used the 7815/7915 pair. I fixed the problem by adding more local supply bypassing near the TL-074 quad op amps. Even foolproof, easy-to-use, three-terminal regulators can oscillate under the right (wrong?) conditions. You'll never know unless you check them with a scope.

A problem I had with a Nelson Pass A-40 power amplifier is also worth relating. Pass did everything he could to make its construction possible for the novice, even if no test equipment was available. If you didn't have a voltmeter to check DC offset, you could put a 470Ω, 1W resistor across the speaker terminals. No heat = safe offset.[4] When I measured harmonic distortion, one channel was excessively high above 12W output; below 10W the amplifier measured just as Pass specified.

The problem was amplifier oscillation caused by insufficient local supply bypassing. The Old Colony kit contained much larger heatsinks than those used by Pass in his prototype, so the leads to the output transistors were rather long. Adding bypassing from the output transistor cases to local ground solved the problem, and the amplifier sounded excellent.[5] Without the proper test equipment, I would never have known the amplifier was malfunctioning, and would probably have blamed the bad sound on the design. The design was not the problem, however; my particular layout created a situation the designer did not foresee.

Since Walt, Jan, and I are well aware of the potential for oscillation, it would be irresponsible of us to avoid stressing the test equipment issue. Every hobby requires an investment in the right tools and equipment, and good test gear is more affordable than ever. MCM Electronics' Tenma line includes a dual-trace "Trainer" scope with a 20MHz bandwidth (#72-905) for $335. They also have a complete line of digital voltmeters.

Heatsinks

In Part 3 Jan makes some suggestions for heatsinking the pass transistors, Q1 and Q2 (Q1 in Walt's diagrams). Jan uses a TO-220 heatsink made in Switzerland by Fischer Electronic. Since there isn't an exact replacement in the US, he recommends Aavid's HS-112. When I installed the ±14V regulators in my modified Adcom 565 preamp, I found the HS-112 inadequate for this load, which is approximately 100mA.

There's a fairly easy solution to this problem. The HS-112 has three fins per side. Aavid also makes the HS-114, with six fins per side. For even more heat dissipation, Aavid's HS-113 "booster" is used in conjunction with either the HS-112 or HS-114. It mounts on the top of the transistor, so heat can be dissipated from both sides of the metal tab. I recommend this combination for higher current applications.

The 1.5-inch-long HS-114 overhangs Jan's board, which may not work in some physical layouts. I find that it's very easy to cut off one or two pair of fins with a band saw or hacksaw to custom fit the heatsink to my own requirements. Be careful not to bend or twist the heatsink when you make the cut.

If you use a hacksaw, I recommend clamping the heatsink to a wood block with a #6 sheet metal screw and flat washer. Use one of the two holes in the heatsink, and tighten the screw just enough to hold the heatsink in place: you don't want to bend it. Then make the cut with a sharp hacksaw blade on the opposite end of the heatsink. When finished, remove any burrs or rough edges with a small file, and be sure the heatsink is completely free of metal filings. This is really a simple process and takes only a few minutes.

For the Adcom 565 preamp regulators, I trimmed HS-114s to five pair of fins. Four pair works fine for the 5V regulators I built. In both cases I used trimmed HS-114s along with the HS-113 booster. Your exact current requirements will determine just how much heatsinking is needed. With some ingenuity, you can easily fabricate parts from readily available sources. For example, Digi-Key stocks all three Aavid products and ships the same day.

If you ensure that there won't be any electrical contact between the heatsinks and any other point, particularly ground, you shouldn't need to insulate the pass transistors. This shouldn't be a problem in most cases, but make sure the ground plane on the PC board doesn't touch the heatsink. They were perilously close on the board samples I got from Jan, so I had to trim the positive ground plane. A single-edge razor blade works fine for this.

Use the insulators if you have any doubts. (You'll get slightly better heat transfer without them, however.) Jan suggests placing a plastic spacer between heatsink and board to solve this problem. This also isolates the board and other components from the heat, which is worth considering in high-current situations. Always use white silicone thermal compound, such as GC Electronics 8109 (available from Mouser or Newark). Metallic oxides contained in the white compounds facilitate heat transfer.

Preliminary Tests

It is worthwhile to bench test your regulators prior to installing them, as a malfunctioning device is much easier to troubleshoot before it is buried in a chassis. The raw supply I built for this purpose is shown in *Fig. 1*, with a parts list in *Table 1*.

This ±13V supply can be used for testing 5V and 14V regulators. To test the latter, use the full 26V available between the positive and negative rails; 5V regulators can be fed from the 13V rails. When conducting your tests, be careful to observe correct input polarity: you can damage the op amp and transistors with reversed polarity. The 1k bleeder resistors are overrated at 1W, but they stay cool, and the stiff leads make solid connection points for clip leads.

For bench testing, omit the remote sensing by jumpering load output to sense, and load ground to sense ground. You should also put a resistor across the output to pull 75–100mA from the regulators. Use 150Ω, 1W for the 14V versions, and 50Ω, 1W for the 5V ones. The load resistor values can be tailored to match the current drain in your specific application.

I find a Variac (VARIable AC transformer), shown in *Fig. 1*, extremely useful for testing. If you put a digital voltmeter across the regulator outputs, you can slowly increase the Variac's AC output while monitoring the regulator's DC output. When testing a positive regulator, be sure the output is actually going positive as you begin turning the Variac. If it isn't, power down and find the problem. The output of a negative regulator should begin to go negative as soon as AC is applied.

It's easy to reverse polarity on a bench setup connected with clip leads, but if you make a mistake the Variac avoids potential disasters. It also allows you to adjust the DC input to the regulator, duplicating the voltages which will be present in your equipment.

Once you have verified correct DC performance, check the regulator for oscillation. Set your oscilloscope for

TABLE 1

RAW DC TEST SUPPLY PARTS LIST

TRANSFORMER	
18V CT, 2.0A	(Mouser 41FJ020)
BRIDGE	
6A, 100PIV	(Digi-Key PB61-ND)
CAPACITORS	
0.47µF/100V	Panasonic V-series (Digi-Key P4733-ND)
2,200µF/25V	Panasonic HFQ (Digi-Key P5716-ND)
RESISTORS	
1k/1W	Yageo metal oxide (Digi-Key P1.0KW-1BK-ND)
VARIAC	
Tenma 10A	Variable Autotransformer (MCM 72-110)

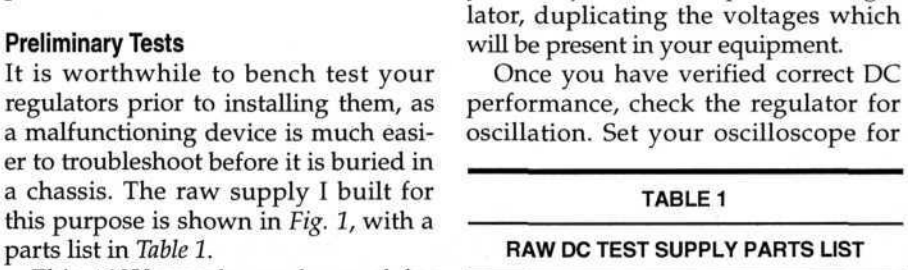

FIGURE 1: Raw supply for bench testing regulators prior to installation. The Variac is recommended to avoid damage if the circuit is not operating properly.

maximum sensitivity and minimum time base. On my scope these are 5mV and 0.2μs per division. Always set the scope for *AC coupling* in these tests. Also, if your scope's input coupling selector has a ground position, *make sure it is not in this position*. Check that no oscillations are present after the regulator has reached its rated DC output voltage.

You can check dropout voltage by connecting your digital voltmeter from the input to the output of the regulator. Set your scope to 20–50mV/division sensitivity and 2.0ms/division time base, and connect it to the regulator output. As you decrease the Variac output from 117V AC, you'll see the voltage difference between the regulator input and output decrease proportionally.

The scope trace will remain a straight line until the regulator "drops out" of regulation. At this point, 120Hz sawtooth ripple will appear on the scope, and will quickly rise in level as the input voltage is dropped further. The dropout voltage is the input/output voltage differential at the point where the ripple just barely appears. With a 100mA load, dropout can be anywhere from 1V to 1.8V in a properly functioning regulator. (There's more on the dropout issue later in this article.)

Transformers and Raw Supplies

Whether you use these regulators in a new design or modify existing equipment, you must make some decisions regarding the raw, unregulated portion of your power supply. In the past I have used toroidal transformers for practically all of my audio projects. These devices are extremely efficient, and, since they concentrate the magnetic field in the core, radiate a low hum field. Rick Miller, author of the sidebar on rectifier diode noise which accompanies my Pooge 5.5 article,[6] has been measuring power transformer bandwidths. He concludes that we are barking up the wrong tree with power toroids.

As it turns out, toroidal transformers are wideband devices which are extremely effective at transferring power line noise to equipment. *Figure 2* (prepared by Rick on an Audio Precision System 1) is a comparative frequency response plot of the two transformers. It illustrates the problem quite dramatically. The top, dashed trace is an Avel-Lindberg D-3022 toroidal transformer, which is nearly flat to 200kHz. The bottom, solid trace is a Magnetek FD7-36, a split-bobbin design which is part of their Quick Pack series. The Magnetek is nearly 35dB down at 200kHz, with a –3dB point around 4kHz, while the Avel-Lindberg's –3dB point is well above 100kHz. I don't mean to single out Avel-Lindberg in this example; toroidal transformers from other sources have similar characteristics.

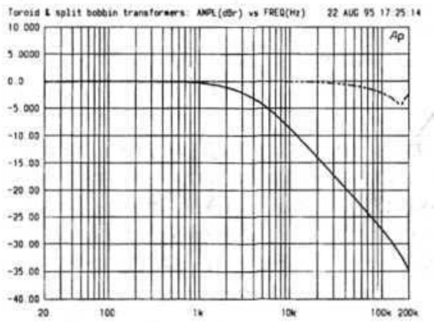

FIGURE 2: Bandwidth measurements on conventional and toroidal power transformers: dashed trace (top) is an Avel-Lindberg D-3022 toroid, flat to nearly 200kHz; solid trace (bottom) is a Magnetek FD7-36, nearly 35dB down at this frequency. (Courtesy of Rick Miller).

Rick's measurements show that Signal Transformers' A-41 series offers even more effective high-frequency noise attenuation. These dual-bobbin designs have two independent primary and secondary bobbins. This greatly reduces the capacitive coupling between them, which is extremely important for attenuation of common mode noise. Split- and dual-bobbin construction eliminates the need for expensive—and not nearly as effective—electrostatic shielding.

For more information on the effects of transformer construction on noise transfer, Rick suggests Topaz Electronics' *Noise Suppression Reference Manual*.[7] It makes two important points: "physical separation of coils placed side by side on separate legs of the magnetic core of a transformer will provide far less capacitive coupling than coils wound directly over one another"; and related to electrostatic shielding, "capacitance around the Faraday shield will still couple enough noise from the primary to secondary to cause problems in sensitive equipment."

The capacitive coupling between transformer windings is inversely proportional to the transformer's hi-pot rating. ("Hi-pot" is short for *high potential*, the point at which the dielectric material—in this case the enamel insulation on the transformer wire and the bobbin itself—breaks down.) The higher the rating, the lower the coupling. Magnetek Quick-Pack transformers have a hi-pot rating of 2.5kV RMS; Signal's A-41 series is rated at 4kV RMS. (Magnetek transformers are available from Mouser; Signal sells factory-direct.)

Beyond the selection of the power transformer, we now recommend raw supplies even more sophisticated than those of Pooge 5.5. A raw supply for ±14V supplies is shown in *Fig. 3*, with a parts list in *Table 2*. A unique feature is the common mode chokes on the DC side of the rectifier bridges, another Rick Miller innovation. These chokes are 56mH Panasonic types, carried by Digi-Key. The 0.47μF capacitors on the input line filter are special 250V AC Panasonic Interference Suppression caps.

Further sonic improvements are noticeable when common mode chokes are used between the rectifier diodes and the input filter capacitors, as in *Fig. 3*. Note the absence of large film capacitors directly across the transformer secondaries. They are unnecessary with the common mode chokes, and can

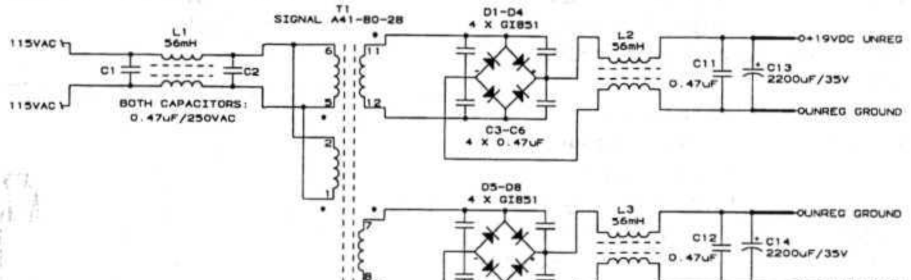

FIGURE 3: Raw supply suitable for use with high-performance regulators. Common mode chokes are used for AC line filtering and DC filtering after the rectifier bridges.

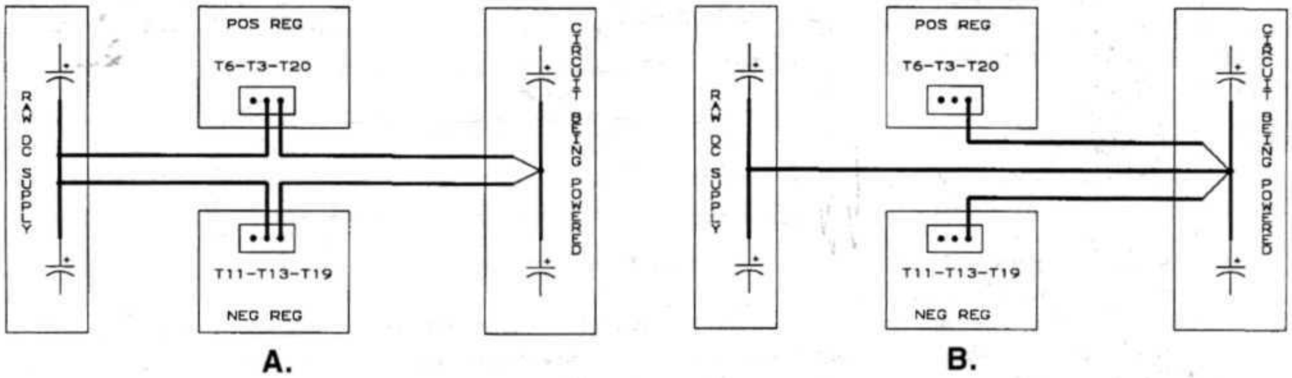

FIGURE 4: Two methods for connecting the regulators in equipment with a common raw DC ground. A: Incorrect method; B: correct method, recommended to avoid a ground loop.

cause high-Q resonance problems with these transformers. As outstanding as these regulators are in terms of line rejection, effective power line filtering and low-noise rectifier diodes are still sonically beneficial.

In Part 3 Jan shows the best method for connecting these regulators to the raw supplies and the powered circuitry. *Figure 3* is consistent with his recommendations, since it has separate bridge rectifiers for the positive and negative raw supplies; the unregulated supplies do *not* share a common ground. If you are working with existing equipment as part of a modification project, you may be forced to use a raw supply with a single rectifier bridge and a common ground.

Figure 4 shows two options for connecting these regulators in such cases. "A" is *not* recommended, since there are two ground paths between the raw supply and the powered circuitry. The correct method is shown in "B," where one ground lead is run from each regulator board to load ground, or the existing equipment's main

TABLE 2

HIGH-PERFORMANCE, DUAL-POLARITY RAW SUPPLY PARTS LIST

L1, L2, L3	Panasonic 56mH common mode line filter (Digi-Key PLK1017-ND)
C1, 2	Panasonic 0.47µF/250V AC interference suppression (Digi-Key P4614-ND)
C3–12	Panasonic 0.47µF/100V V-series (Digi-Key P4733-ND)
C13, 14	Panasonic 2,200µF/35V HFQ (Digi-Key P5751-ND)
D1–8	General Instrument GI-851 (Digi-Key GI851CT-ND)
T1	Signal Transformer A41-80-28

power supply ground bus. I used this method for the Adcom GFP-565 preamp, since it eliminates the possibility of a ground loop.

Op Amps and Decoupling

Walt offers builders a choice of two op amps: Analog Devices' AD848 and AD797. The graphs in Part 2 show the latter to be superior in virtually all aspects of performance. You may wonder just how audible these effects are, but in my listening tests I also found the 797 to be the superior sonic performer. (I elaborate on this later in the article.)

Remember that the op amp is powered from an *unregulated* supply. So regardless of which one you choose, its own power supply can affect the overall regulator performance. In Part 1 Walt provides an optional low-pass decoupling, consisting of a 22.1Ω resistor in series with the op amp supply, and a 120μF electrolytic capacitor added for local bypassing. This R/C combination produces a first-order, low-pass filter with a corner frequency of 60Hz.

In Part 3 Jan discusses the pluses and minuses of powering the op amp through a series resistor. He concludes that, in this application, op amp supply current is neither frequency- nor load-dependent; therefore, no ripple currents will develop across the 22.1Ω resistor. I have heard ±14V regulators both with and without decoupling, and the former is sonically superior. Walt's Fig. 12b shows a dramatic improvement in line rejection with it, with the AD797 performing substantially better than the AD848 at low frequencies. Jan's board accommodates the decoupling, and I highly recommend its use.

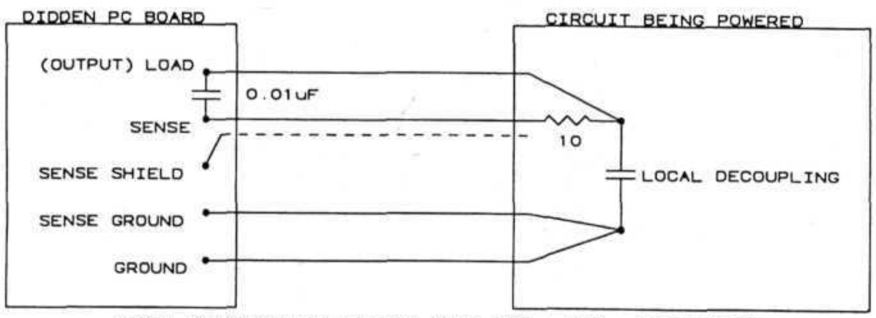

FIGURE 5: Remote sense decoupling scheme. Connections and parts values are the same for positive and negative regulators.

Oscillations and Decoupling

The remote sensing capability is a highlight of these regulators, but the potential for oscillation in the megahertz region exists in any wideband op amp. The AD797 is particularly susceptible. Supply oscillation is governed by any number of layout-related issues, including length and inductance of the remote sensing wiring, shielding characteristics, and the amount of low-ESR local supply bypassing. *There's no way to predict whether the supply will oscillate—each implementation must be tested.*

Once the regulator has been installed, connect your scope probe between load and load ground on the regulator PC board. Use the same oscilloscope settings as previously noted in the preliminary tests. Rotate the triggering until a stable trace appears. A virtual straight line indi-

±5V Supplies Using the Didden PCB

By Walt Jung

The original 5V regulator published as Fig. 9 in Part 1 is a good positive device, capable of very low noise when used with the AD780. Unfortunately, no board design has specifically addressed this circuit for 5V use. In addition, this type of design, which is based on a three-terminal IC reference, cannot be "flipped" to provide negative or −5V outputs. Many modern designs *do* need high-quality ±5V sources, for example, the Youtsey et al mods to the DAC-in-the-Box (*TAA* 4/94, p. 8).

Fortunately, some fairly simple adaptations to the original article's Fig. 8a or 8b can provide the desired functionality to achieve ±5V operation. What is even more fortuitous is that these changes can be readily implemented by simple part substitutions on the Jan Didden PCB design in Part 3.

This adaptation implements the lower output voltage (+) or (−) 5V versions by using a 2.5V reference diode in place of the original 6.9V LM329. Specifically, the industry standard LM336, a two-terminal 2.5V reference IC, allows this. It can simply be substituted in the same footprint as the LM329 on Jan's board. As long as the surrounding support circuitry is fully compatible with the lower voltage operation, this can implement a very high quality +5V or −5V regulator, with the same ease of construction as noted by Gary.

The specific changes to the positive/negative regulator circuits which accomplish these goals are listed here. Note: In adapting the original circuits to 5V output, change *only* the following items; leave all other details as originally published. (Complete part numbers and order information appear in *Table 3*.) In each step, the first reference designation pertains to Part 3, Fig. 2 (positive regulator); the designations in parentheses refer to Part 3, Fig. 3 (negative regulator); the original reference designations to Figs. 8a and 8b from Part 1 are in brackets.

1. Change D1 (D6) [D1] to an LM336 2.5V TO-92 diode type, polarizing it as shown in the original schematic. Special note: Do *not* connect the adjust pin.

2. Change R4 (R14) [R6] to a 2.49k 1% metal film type.

3. Change R20 (R21) [R5] to a 4.99k 1% metal film type.

4. Change X1 (X2) [U1] to an AD797. This is optional in terms of basic functionality, and the circuit also works with the AD848. Do *not* substitute other op amps, as the input CM range must be compatible with 2.5V operation!

5. Delete the D2 and D3 (D4 and D5) [D2 and D3] 1N4148 diodes when/if using the AD797. Retain them if using the AD848.

6. Low-dropout operation is highly recommended for the ±5V regulators, and should be implemented *using all three of the steps outlined above.*

These changes affect DC operation for the most part, so AC performance can generally be expected to be consistent with what has already been published for the original Fig. 9 circuit.

cates the supply is working correctly; an oscillating one won't be subtle. If the regulator is powering digital circuitry, random digital hash on the supply lines is normal. An oscillation will be repetitive, at a specific frequency. A scope with good triggering should enable you to get a firm sync on any oscillation which may be present.

Don't be surprised to see some very low level ripples toward the left edge of the screen, even if the supply is working properly. The probable cause is the test setup's ground lead inductance. To verify, connect the scope probe to the chassis ground near the same point as the ground lead. You should see the same low-level ripples as before, particularly on a wideband scope, but you now know that this is a function of the test setup rather than the regulator.

While I found that 797-based regulators oscillate in some cases and not in others, I was determined to make this op amp work properly. Walt and I agreed on the need to ensure that the 797 could be reliably implemented—*with remote sensing*—in a variety of layouts. To solve the oscillation problem, Walt devised an implementation for decoupling the remote sensing lines at very high frequencies (*Fig. 5*). The polarity of the regulator isn't defined, since both positive and negative use the same decoupling topology. The local AC bypass removes the remote sense feedback path, and its associated phase shift, at very high frequencies.

First, solder a 0.01µF Panasonic V-series stacked film capacitor between the load (output) and sense pads on the PC board. You can solder this small cap to the board's foil side. Use insulating sleeving, particularly on the negative board where the cap must jump over a PC trace. Next, insert a 10Ω, ¼W resistor in series with the remote sense line *at the load*. This R/C network results in a –3dB point of 1.6MHz; the regulator still qualifies as a wideband audio device, but the chance of oscillation is greatly minimized.

With remote sensing, I recommend this decoupling regardless of which op amp you choose. Since no one can predict the effect of every possible layout and implementation, you must still check the supplies with a scope. The 10Ω resistor actually changes the DC gain of the op amp and raises the output voltage. The change is very slight, though –10Ω is the tolerance of the 1k feedback resistor. Even with worst-case tolerances, a 5V regulator is well within safe operating limits for logic circuits.

A final note on oscillation: even regulators built with the AD848 can oscillate if a low-Z film cap is placed directly across the regulator output (as noted in Part 2, p. 34). *It is very important to build the PC board as specified!* Don't be tempted to add any film bypassing to the input or output. A low-Z film cap across the output electrolytic will virtually *guarantee* regulator oscillation. If the regulator is within 2" of the powered circuitry, don't use any local film bypassing, either. Local film bypass capacitors should be at least 3–4" from the PC board. In difficult circumstances a ferrite bead between the regulator output and the load can be helpful. Jan's sidebar offers some helpful suggestions for oscillation problems.

Dropout Warnings

When I first tested regulators built with the AD797, I found that the dropout voltages were not as low as those noted by Walt (his measurements were based on the AD848).

With a 100mA load, my positive regulators measure as high as 2V, whereas 1.5V or less is typical of the AD848, even with loads of several hundred milliamps. The 797 requires more input headroom than the 848, primarily because of differences in its output stage design.

The op amp in Walt's Fig. 8a must bias up to nearly the same DC potential as the output DC voltage, since the V_{BE} of Q1 and the V_F of D4 essentially cancel. As the input voltage V_S is lowered, the output swing limitation of U1 can limit the regulator dropout if the op amp voltage limit with respect to its supply rail is significantly higher than 1V (the dropout of the current source, Q2, D5, and R7). The 797's output can't swing as close to its rail voltage as the 848, which results in higher dropout voltage for the regulator.

The following enhancements are suggested to improve the dropout voltage with both the AD797 and the AD848 op amps. (Part numbers are listed in *Table 3*.) These changes are listed in order of decreasing sensitivity. In each step, the first reference designation pertains to Part 3, Fig. 2 (positive regulator); the second designation in parentheses refers to Part 3, Fig. 3 (negative regulator); the original reference designation to Figs. 8a and 8b, from Part 1, appears in brackets.

1. Change D7 (D9) [D4] to a Panasonic 30mA green LED. This enhances the output swing of the op amp. Don't be tempted to substitute another LED: the 2V drop across the specified part serves as a level shift, and is critical.

2. Lower R20 (R21) [R5] to 10k or 12k. This yields a small improvement, typically 0.05–0.1V. Note that Jan has already made this change in Part 3. Don't worry about this unless you built a regulator from Walt's Figs. 8a or 8b, and low dropout is an issue in your application.

3. Change current source Q3 (Q4) [Q2] to a device with lower V_{SAT}. This improves dropout by about the same amount as the resistor change in step 2. Recommended transistors are PN2907A (PNP–Q3) for positive regulators and PN2222A (NPN–Q4) for negative.

With all three changes, the dropout voltage will be close to 1V, but the first two steps will get you most of the way. You don't need to change Q3 and Q4 unless you absolutely must squeak out another 0.1V or so. Low dropout won't be important if your raw input rail voltages are high enough. The flip side of this coin is heat dissipation. One of the advantages of low-dropout regulators is they enable you to use lower raw DC voltages. Most of the pass transistor's heat is produced supplying current to the load, rather than dropping voltage. Remember that for a given current drain from the regulated output, the heat will increase as the raw DC voltage is raised.

TABLE 3

PARTS LIST FOR MISCELLANEOUS REGULATOR CHANGES

REMOTE SENSE DECOUPLING	
0.01µF/50V	Panasonic V-series capacitor (Digi-Key P4513-ND)
10Ω/¼W, 1%	Yageo metal film resistor (Digi-Key 10.0X-BK-ND or Roederstein MK2)
LOW-DROPOUT MODIFICATION	
30mA	Panasonic green LED (Digi-Key P309-ND)
	PN2907A transistor, TO-92 case (Digi-Key PN2907A-ND)
	PN2222A transistor, TO-92 case (Digi-Key PN2222A-ND)
10k, ¼W, 1%	Yageo metal film resistor (Digi-Key 10.0KX-BK-ND or Roederstein MK2)
±5V VERSIONS	
	National Semiconductor LM336BZ-2.5 (Digi-Key LM336BZ-2.5-ND)
2.49k, ¼W, 1%	Yageo metal film resistor (Digi-Key 2.49KX-BK-ND or Roederstein MK2)
4.99k, ¼W, 1%	Yageo metal film resistor (Digi-Key 4.99KX-BK-ND or Roederstein MK2)
SOURCES FOR OTHER REGULATOR PARTS	
Analog Devices AD797AN and AD848JN (Newark Electronics, both items listed in current catalog #114)	
Panasonic 120µF/25V HFQ capacitors (Digi-Key P5698-ND)	
0.1µF/50V Panasonic V-series capacitors (Digi-Key P4525-ND)	
LM329 Reference (Digi-Key LM329DZ-ND)	
1N4148 Diodes (Digi-Key 1N4148-ND)	
2N5087 Transistor (Digi-Key 2N5087-ND)	
2N5089 Transistor (Digi-Key 2N5089-ND)	
D44H11 Transistor (Mouser 570-D44H11)	
D45H11 Transistor (Mouser 570-D45H11)	
Roederstein MK3 series, 1k, 0.5W (Michael Percy)	

Other Voltages

These regulators can be adjusted for other output voltages, though ±14V and ±5V should cover most audio applications. Table 1 in Part 2 supplies alternate resistor values for voltages from 10V to 18V.

Some of you may be tempted to raise the rail voltages beyond ±14V for preamp power supplies. With the gain

So It Oscillates–Now What?

By Jan Didden

As Gary explains, you should definitely check your supplies for oscillations. They are not inherently unstable, but with so many variables there is always a chance. Use the following checklist to systematically review and remove the possible causes.

1. Assuming you use the proposed PCB, did you build it as described in Parts 3 and 4? No extra film caps should be placed at the regulated output!

2. Have you limited the lead lengths as much as possible? Preferably, they should be no longer than 4 or 5". Be sure to twist the raw supply lines and the regulated load connections, *but not to each other.* Do not connect the sense shield to the ground point at the load, only at the PCB.

3. Mount the board(s) over a metal enclosure wall or partition, as close as possible. This will decrease any oscillatory tendencies, and also improve the noise figure.

4. Check the circuit to be powered for excessive decoupling capacity. With these very low impedance regulators, more than 100µF or so is overkill, and promotes instability. If you use film caps at the load, don't make them larger than 1µF or so. I know it goes against the grain to actually remove a film bypass cap. Although they are a solution to many problems, in this application they can actually cause problems.

5. The remote sense decoupling filter should take care of any remaining oscillations, but in persistent cases you can increase the resistor value to 22Ω and the capacitor to 0.015µF, with negligible impact on performance.

6. The AD848 in this application is a bit more stable than the AD797, so if all else fails this could be a solution. As Gary notes, this is not as good sonically.

7. Finally, don't get discouraged. We have built many of these regulators, and every one could be persuaded to work as advertised.

determining resistors set at 1k each, the op amp has a voltage gain of 2. When the reference is the 6.9V LM329, this actually produces 13.8V. The 10Ω resistor in the remote sense decoupling brings it up to around 13.9V.

In most cases, there's no need to operate preamp power supplies at higher rail voltages. Even with these values, my modified Adcom GFP-565 outputs close to 8V RMS before clipping. Since most power amps clip with 2.5V input, it is pointless to raise the preamp rail voltages. Contrary to what some believe, higher rail voltages won't give you more "headroom" if the next device (i.e., your power amp) can't handle the input signal.

Listening Evaluations

A set of ±14V regulators has been installed in my extensively modified Adcom GFP-565 preamp for over six months. Throughout most of the modification process (subject of a future article), I have used a second, unmodified GFP-565 for comparison. Installing the high-performance regulators in the 565 affected nearly every aspect of performance, with the most striking improvement in the area of dynamics. I was amazed to find that, even though the line stage gains in both units were identical, the modified 565 actually played louder than the stock preamp. This may seem strange at first, but there is a logical explanation.

The new power supplies offer a sense of unrestricted dynamics; full orchestral crescendos are rendered with a sometimes overwhelming impact. Subjectively, the original supply regulators compress orchestral *tutti* passages, whereas the modified preamp releases them with full force. I was repeatedly lowering the volume relative to the stock preamp to achieve the same subjective playback levels. This was frustrating, since I was now playing most of my reference CDs with the volume around 9:00, leaving little room for adjustment. Walt and I have actually lowered the voltage gains in our line stages from 11 (a 10k/1k feedback combination) to 5 (4k and 1k) to allow a greater range of volume control adjustment.

There's more to the dynamic improvements than sheer volume, however. With the new regulators, the preamp sounds effortless no matter how taxing the source material. Even with the most demanding recordings, it remains clean and detailed, free of harshness or edge.

These super-quiet regulators also lower the subjective noise floor: low-level dynamics aren't artificially elevated, they simply descend effortlessly. In "Siegfried's Funeral March" from Wagner's *Götterdämmerung* (Solti, London CD 414-115-2), it is easy to miscalculate the dynamic contrasts. If you adjust the volume so the soft timpani notes (CD 3, Track 7) are at a comfortable level, the *fortissimo* at the climax can be unbearably loud. With the climaxes set at a realistic level, the

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entire dynamic range sounds much closer to a real concert hall experience.

The new analog regulators also increase soundstage size, both left-to-right and front-to-back. Prior to installing them, I had difficulty separating the bass drum from the timpani in "The Hut on Fowl's Legs" from Mussorgsky/Ravel's *Pictures at an Exhibition* (Reiner, RCA Victor Living Stereo CD 61958-2, Track 14), not in terms of timbre but of localization. The placement of these instruments is now reproduced with pinpoint accuracy, and considerably deeper in the soundstage than before. Inner detail and articulation are also improved.

To compare the AD848 and AD797 op amps, I soldered machined-pin, gold-plated sockets to the ±14V regulator board. I then soldered the op amps to gold-plated headers (with Caig ProGold contact conditioner on the header pins) for a gold-on-gold contact.

The 797 reveals greater inner detail from recordings than the 848. Its sonic presentation is also a bit more "laid back," more natural and musically convincing. The soundstage is not only deeper, it seems to have been moved back slightly. The 848's presentation is closer and more "forward." The line rejection measurements bear out these differences, and it's not surprising that the results of improved line rejection are similar to those of better power line filtering.

DAC Regulators

I installed and evaluated the new digital regulators in the DAC960 in three phases: a +5V regulator for the demodulator board; +5 and −5V regulators for the TDA1541A DAC chip; and a dedicated −15V supply for the TDA1541A. All digital regulators use the AD797. Instructions for this process are beyond the scope of this article. If there is sufficient interest, I'll prepare an "Ask *TAA*" column on the subject. Write to me (c/o *TAA*) if you would like to see this published.

Based on my experience upgrading the original digital supplies, I expected similar improvements from these changes, and the DAC regulators would offer "more of the same." My assumptions were wrong. Each of the upgrades produced different results. All listening evaluations were conducted with Analog Devices AD1890 evaluation board for jitter suppression.[8]

The real surprise is the demodulator regulator, which yields an improvement in dynamics and bass similar to the analog regulators in the 565 preamp. The effect on weight and impact in the bass region is like getting better subwoofers or a new power amp. The bass drum in Reiner's *Pictures* is deeper and more powerful. In Ernest Ansermet's recording of Ravel's *Alborada del gracioso* (London CD 433-717-2), the bass drum, while always quite impressive, is now even heftier than I had realized.

I was completely surprised at the ability of a digital regulator to make such a striking improvement in the bass. This is undoubtedly jitter-related, since the demodulator board's input switching circuitry and input receiver should have a significant effect on jitter performance.

The Ansermet recording is also incredibly clean and well-defined, not just in the bass but across the entire spectrum. The ±5V supplies for the 1541A DAC result in improved articulation, detail, and the sense of air and space around the instruments. Ravel's colorful orchestrations are reproduced with an openness and transparency which are uncanny, and the delicacy of his scoring is far more evident here than in my British-pressed London Treasury Series LP, which sounds dull and lifeless by comparison (most of London's "Made in England" Richmond and Treasury Series LPs were extremely good; when they began pressing these LPs in the US in the mid-1970s, the sound quality became abysmal).

Track 2 of Reiner's *Pictures*, which I regularly use as reference material, has a series of four string *glissandi* bowed close to the fingerboard. Prior to installing the ±5V DAC regulators, the effect sounded merely like fingers sliding up and down the strings. Now I can clearly hear the subtle articulations of the bow. Such a soundstage subtlety often goes unnoticed. The four *glissandi* begin with the violas, move to the celli, then the second and first violins. On a less refined D/A converter, there appears to be a general movement from right to left. With these regulators, the exact placement is clear: right, far right, left, far left. Musical subtleties, carefully notated by Ravel and superbly executed by the Chicago Symphony, are revealed in all their glory by the DAC960.

I have noticed an amazing number of tape edits on CDs made from analog sources, which, prior to installing the DAC regulators, had escaped my attention. One example is the EMI reissue of Boris Christoff's 1962 stereo remake of Mussorgsky's *Boris Godunov* (André Cluytens, CDS7 47933-8), during Boris' Monologue in Act II (CD 2, Track 6). Another occurs in the Solti *Götterdämmerung*, in the final scene in Act II (CD 2, Track 12). Quite a number of tape edits are audible on the Decca/London operas produced by John Culshaw. Some of these edits were not obvious until I replaced the DAC regulators. In fact, the DAC960's ability to resolve minute details is so great that I sometimes hear off-axis microphone colorations as the singers move around the soundstage.

Icing on the Cake

The sonic effect of the new digital regulators is nothing short of dramatic, every bit as important as the analog regulators in my preamp. After spending nearly a week with the DAC960 in this state, I decided to give the TDA1541A a dedicated −15V supply. While this effect was more subtle, it was nonetheless worthwhile. Low-level resolution and detail were enhanced a bit further, with the last ounce of performance squeaked from the 1541A.

The −15V supply is critical, since it is the voltage source for the DAC's current outputs. If you check this sup-

SOURCES

Digi-Key Corp.
701 Brooks Ave. S., PO Box 677
Thief River Falls, MN 56701-0677
(800) 344-4539, FAX (218) 681-3380

MCM Electronics
650 Congress Park Dr.
Centerville, OH 45459-4072
(513) 434-0031, FAX (513) 434-6959

Michael Percy Audio Products
Box 526, 170 Highland
Inverness, CA 94937
(415) 669-7181, FAX (415) 669-7558

Mouser Electronics
958 N. Main St.
Mansfield, TX 76063
(800) 346-6873

Newark Electronics
(312) 784-5100
(Call for branch nearest you)

Signal Transformer
500 Bayview Ave.
Inwood, NY 11696
(516) 239-5777, FAX (516) 239-7208

ply line with a scope, you'll see some low-level digital hash. This will also appear on the –15V rails to the analog circuitry if they share a common supply. Part of the perceived improvement may be due to removal of noise from the analog supply rail.

Some of you may wonder why I continue to modify a digital-to-analog converter that uses an "obsolete" digital chip set. Some truly wonderful digital filters and D/A converter chips are now available, with 20-bit resolution, 8× oversampling, and such. Several manufacturers produce D/A converters equipped with HDCD decoding capability.

Having upgraded the regulators in the DAC960 and heard their sonic effects, I honestly believe no one realized the full potential of the Philips 16-bit chip set while it was in production—least of all Philips. I recently auditioned an $800 HDCD D/A converter made by a leading American manufacturer which was inferior to my DAC960 in every respect, even before the high-performance regulators were installed. It used three-terminal adjustable regulators for the analog circuitry and 7805 types for the digital circuits.

There is a lesson to be learned from all of this: digital circuitry, no matter how sophisticated, will never perform to its potential with cheap, low-end power supply regulators. Manufacturers of both digital recording and playback equipment need to seriously reconsider the criticalness of power supply regulation to the performance of high-end digital circuitry. If you own a DAC960 modified to Pooge 5.5 standards, I believe the digital supply upgrades are well worth installing. You may find that the DAC960—once again—outperforms many expensive products with more sophisticated digital circuitry.

Conclusions

A great deal of discussion about the virtues of shunt regulators has occurred in the audio press over the past few months. Since these devices require a series resistor terminated by a shunt capacitor, they automatically provide low-pass filtering of power line and rectifier noise. As important as this may be, several other critical performance areas must be addressed. Before choosing shunt regulators for your next project, I suggest verifying their measured performance in *every* area, as discussed in Part 2 of this series.

Walt Jung's high-performance power supply regulators set new standards of performance in both analog and digital applications. They require a great deal from the builder, yet I have found the sonic improvements worth every hour spent on this project. I hope that you agree. The cumulative improvement in my audio system has truly been a revelation. ■

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