

► In Praise of Wall Warts

By Paul J. Stamler

These often-overlooked, but vital, little boxes are capable of more than you think in your electronic projects.

You know them—the small, squarish plastic boxes that plug into a wall socket or power strip and send power to a multitude of electronic products. They're often objects of contempt, derisively branded "wall warts"; their presence in a design is often considered a herald of cheapjack design and construction, even though they've been used in such acclaimed audio products as FMR Audio's "Real Nice Compressor."

Why should serious audio constructors bother with wall warts? To answer that question, you first must ask why manufacturers use them in the first place. The answer, in one word, is insurance.

Take a look at the electrical and electronic equipment in your home. If you live in the US, it's almost sure to have a printed, engraved, or stuck-on label reading "UL Approved." "UL" stands for Underwriters' Laboratories, an organization set up by the insurance industry to test and certify electrical equipment for safety. (If you live outside the US, you'll find similar logos for parallel certification programs, such as the European "CE.")

Equipment with a UL label is presumed safe to plug into a wall socket. Conversely, gear without the label is sometimes presumed by insurance companies not to be safe. In extreme cases, if a house catches fire and a piece of non-UL equipment is found in the ruins, insurance companies may be reluctant to pay the claims.

So why don't manufacturers have everything approved by UL? Money. Get-

ting a piece of equipment tested and certified by UL can cost thousands of dollars, especially if they demand design changes. For a small company, that's prohibitive.

Many choose to punt. UL's chief concern is what actually plugs into the wall and connects to the AC mains, which in electronic equipment is the power supply. Instead of designing their own supplies and submitting them for UL approval, manufacturers will buy pre-built supplies from a company that has already gotten the magic sticker. (How can that company afford it? Well, they're not building just a few thousand a year. Instead, they're building hundreds of thousands, for a multitude of products, and selling them to all sorts of companies, from Joe Blow's ElectroWidgets to Radio Shack and Sony.)

In other words, they're using a wall wart, or its snake-that-swallowed-a-brick cousin, a line lump.

Does this matter to you? If you're building DIY gear for your home stereo it might or might not. Different insurance companies have varying policies (pardon the expression) about UL approval. But if you're running a home studio, for example, where outside clients come in to perform and pay for your recording services, it's an issue. If you use DIY equipment in a home-studio context, you should probably get to know and love the wall wart, and learn to use it effectively.

AC/DC

In this article I mostly talk about AC wall warts (basically transformers in a box) rather than the more common DC devices, which are problematic for many applications.

In the first place, most solid-state circuits these days use bipolar supplies. To power them from a two-terminal wall wart requires the designer to produce some sort of artificial ground halfway between the wart's + and - voltages, and to keep that ground stable. DC wall warts usually come in a maximum voltage of $24V_{DC}$, which means the most you can get from them in a split supply is $\pm 12V_{DC}$, and that's without benefit of regulation. This could limit headroom.

The warts could also power DC-DC converters, but these incorporate switching circuits that can generate all sorts of high-frequency garbage, not something you want floating around inside your chassis. Some DC wall warts, in fact, are switching circuits themselves.

Besides, most DC wall warts are mediocre; they lack the good-design touches you've come to expect in high-quality gear. Instead of large, high-quality, well-bypassed filter capacitors, they use small, cheap caps with no bypasses. They don't use fast-switching, low-noise diodes, nor do they incorporate snubber circuits to minimize diode switching noise. Typically they incorporate no spike-filtering protection.

AC wall transformers offer surpris-

ing flexibility, and can be made to sit up and do tricks, including multiple supplies from a single wart. You can even derive plate voltages for vacuum tube circuits from a low-voltage AC wall wart. Because the user chooses rectifiers and filter components, they can be as good as those in a more conventional circuit.

BASICS

First, consider connections. The near-universal connector for a wall wart's umbilical cord is a round plug, with an inner diameter of 2.1mm or 2.5mm and an outer diameter of 5.5mm. The cord connector is normally female, and the chassis connector is normally male. (This is the opposite of the convention for signal connectors such as XLRs; the idea of making the cord connector female is that it's safer to carry live voltage back inside a hole than on a prong. The same principle applies to AC wall sockets.)

Where can you find chassis jacks? (When I talk about specific parts, I'll limit myself to devices available in the US, because those are what I know about. Similar parts are made and sold all over the world.) Switchcraft sells the 712A and 722A connectors (for $2.5 \times 5.5\text{mm}$ and $2.1 \times 5.5\text{mm}$ plugs, respectively). Both have metal sleeves, so they must be insulated from the chassis by $5/16"$ I.D. shoulder and flat washers. Mouser, Jameco, and Digi-Key all stock these jacks for about \$2.40 apiece.

How about the warts themselves? Digi-Key has a few, but Jameco Electronics has the mother lode. Jameco's catalog 273, pp. 197-8, lists 37 different "AC-to-AC Wall Adapters," all but two carrying UL approval. Output voltages range from $9V_{AC}$ to $24V_{AC}$, with current ratings up to 1.9A. Prices—under \$15—are very reasonable.

BALANCED RAILS

For a simple example, consider a $\pm 15V_{DC}$ regulated supply for use with op amps or similar solid-state circuits. That's a 30V spread, even ignoring the extra needed for regulators. Will a wall wart provide enough voltage?

One possibility which I don't like is to use a voltage doubler (Fig. 1). They're notorious for poor load regulation, and because each leg of the rectifier is basically a half-wave design, ripple is high

and equal to the line frequency, rather than $2\times$ the line frequency as found in a full-wave rectifier. This means a given filter capacitor is only half as effective in removing ripple.

Instead, I'll do something more practical for a DIY designer than a commercial manufacturer: I'll use two identical wall warts.

Without going through the math, once I allow for diode, filter, and regulator drops, plus provide some margin for low line voltage, I find that I want $18V_{AC}$ on each leg of the supply. (You can just squeeze by with $16V_{AC}$, but at the cost of poorer filtering and less undervoltage margin.) Jameco's catalog lists model #121216 from ReliaPro, giving $18V_{AC}$ at 1000mA. They're \$9.85 each, or \$19.70 for a bipolar supply.

How to hook them up? One possibility is shown in Fig. 2: the two transformers' secondaries are wired in series to form a center-tapped $36V_{AC}$ transformer. With wall warts, this means connecting the tip terminal of one chassis jack to the ring terminal of the other, and connecting that junction to the main ground point of the power supply. That works fine as long as the two wall warts operate with the same polarity—in other words, the voltages on tip connections go up and down together, rather than in opposite directions.

Can you rely on that? These are mass-market items, normally used singly, and there's no particular reason for a manufacturer to care about polarity. Besides, not every wart comes from the same manufacturer.

Because of this uncertainty, I'd rather

use the two warts as shown in Fig. 3, connected to separate diode bridges. In this circuit, wart polarity doesn't matter, and the cost of four extra diodes seems pretty modest for the added peace of mind.

(I'm planning another article on power supply design that will describe a triple supply board designed to allow either center-tapped or separate windings. Stay tuned!)

One drawback to wall warts is their lack of built-in protection against major overvoltages and spikes in the line AC. A $.01\mu\text{F}$ 1kV ceramic disc capacitor in the power strip will help absorb RF, but it's possible to also add surge absorption to the output of a transformer, including a wall wart. I assume $\pm 10\%$ variation in line voltage, so adding a metal-oxide varistor (MOV) or similar clamping device with an AC rating 20% over the nominal voltage is reasonable. (Before you choose the MOV, though, check the actual voltage of the wall wart under full load from the supply and audio circuits; if you're drawing only a fraction of the transformer's rated current, its output voltage may already be higher than nominal. Pick an MOV 20% higher than the wall wart's real output under load when the wall socket is at nominal voltage.)

You can install Hagerman-style snubbers on the outputs of wall warts, just as you can on the secondaries of conventional transformers,¹ and you can place fuses in the leads from the wall warts' chassis jacks to the supply, rated at the transformers' current rating.

There's another way to make wall warts produce \pm supplies; I'll work my way around to that.

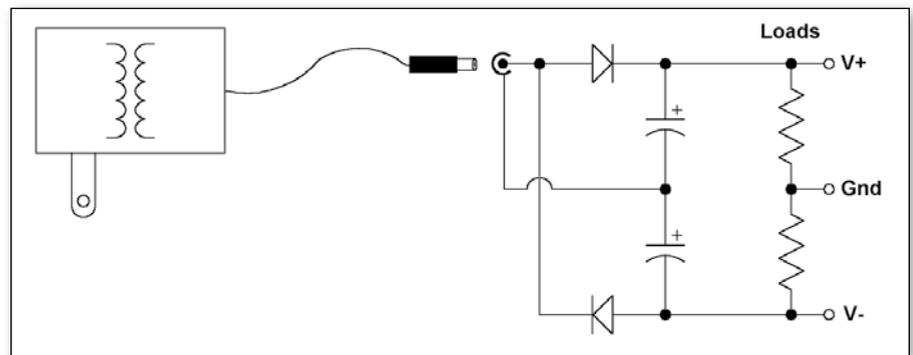


FIGURE 1: Wall wart used with voltage doubler. In this and subsequent drawings, resistors hanging on the DC outputs of the supplies represent their loads. Note that the ground is produced at the junction of the two legs of the load, not within the supply itself.

FILAMENTS AND FLOATING

Next, consider a pair of regulated DC supplies for tube filaments, each $6.3V_{DC}$, $1.2A$. Voltage amplifier tubes normally have their filaments referenced to ground, but cathode followers and similar circuits lift their cathodes as high as $+160V_{DC}$. This can cause problems; every tube type has a maximum heater-to-cathode voltage rating, typically $90V$, and the tube can misbehave seriously if that rating is exceeded.

The solution is to hoist the filament supply's reference up $60-80V_{DC}$ above ground, usually by hanging a voltage divider on the plate supply. With wall warts, this is easy, as shown in **Fig. 4**. Here the first wart drives the filaments of voltage amplifier tubes; its supply has its common terminal grounded. The second wart drives the filaments of cathode-follower tubes; its common terminal is connected to a voltage divider, similar to that found in my Gamp supply.² Note that while this illustration shows a negative common, the method works just as well with a circuit having a positive common.

OK, which wall warts? Again without going through the math, I use a $12V_{AC}$ transformer to generate $6.3V_{DC}$, regulated. Jameco lists several $12V_{AC}$ devices; I'd go for cat. # 167151, rated at $1500mA$. A pair of these will cost \$15.18.

PHANTOM POWER

Time to get fancy with a $+48V_{DC}$ $30mA$ phantom power supply, used to supply juice to condenser microphones. Immediately you're faced with a problem: This requires about $45V_{AC}$ from the power transformer, and I haven't found any such wall warts on the market.

What to do? One solution is a voltage doubler, which would work with a $24V_{AC}$ wart, but I've already said I don't like those. Besides, this raises a practical question.

I have a strong prejudice in favor of making equipment idiotproof. This is because I sometimes work in situations where I'm sleep-deprived, and my higher cerebral functions become—shall we say—dulled (I've called this “chimp mode” in previous articles). In a wall wart context, this translates into a design limitation: If a device is powered by multiple wall warts, it should be impossible to plug the wrong wart into the wrong jack.

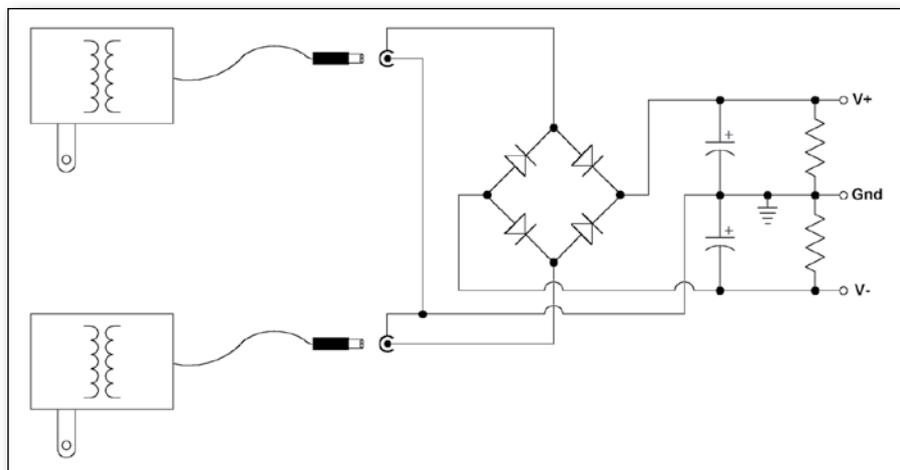


FIGURE 2: Two wall warts connected in series to simulate a center-tapped transformer.

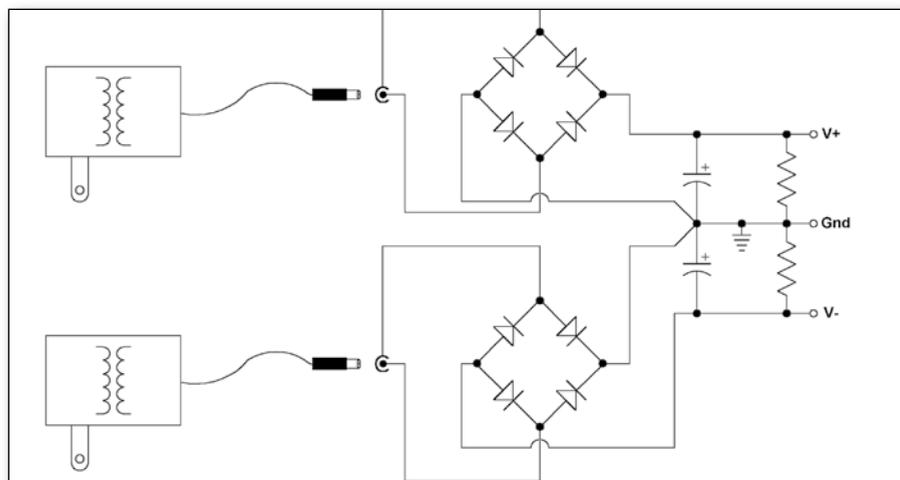


FIGURE 3: Two wall warts with separate diode bridges.

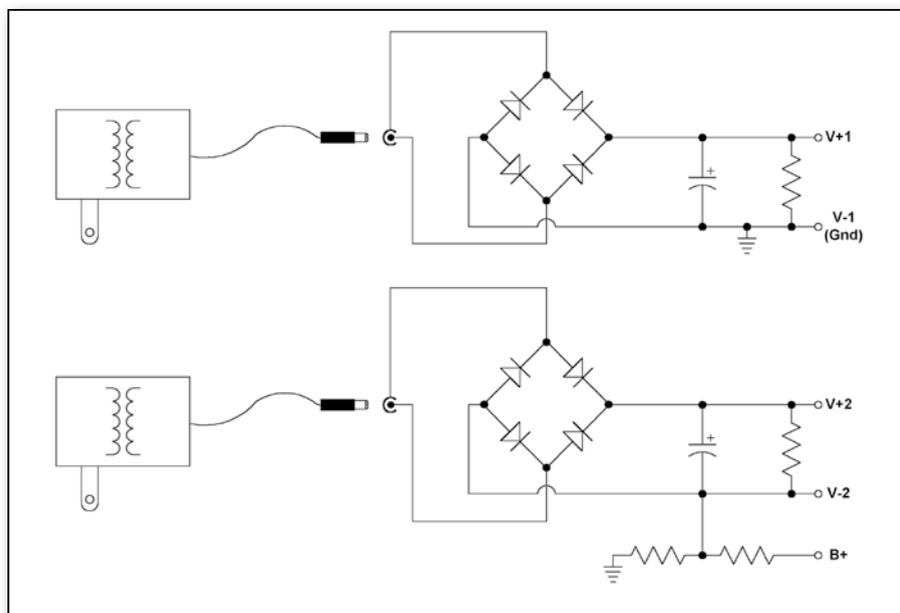


FIGURE 4: Two filament supplies for tubed circuits; the first is referenced to ground, the second to a voltage divider from the plate supply, scaled to hoist the filament about $80V$ above ground.

Insurance against Murphy's Law, if you will.

One way to do this is to make the jacks different—use $2.5 \times 5.5\text{mm}$ jacks for one or two warts, and a $2.1 \times 5.5\text{mm}$ jack for another. That certainly works, but it requires a bit of thinking, and also opens the possibility of an operator in chimp mode (me) trying to shove the wrong plug in the wrong hole and bollixing up the whole works.

A more elegant solution is to design so that all the wall warts feeding a box are identical—any wart can plug into any jack without problems. How do you do that?

THINKING INSIDE THE BOX

Say you wanted to add the $+48\text{V}_{\text{DC}}$ phantom supply to the two tube filament supplies described in the previous section. They use 12V_{AC} warts, so you'll need to use the same for the phantom supply. To turn 12V_{AC} into the 45V_{AC} needed for the phantom supply, use an additional transformer located inside the audio chassis, connected to the external wall wart. Is this kosher? Yes—UL cares about what's plugged into the wall, not what's on the other end of the cord.

I said before you'd need 45V_{AC} on the phantom supply; to get that from 12V_{AC} you'll need a stepup transformer with a ratio of at least $12:45 = 1:3.75$. One easy way to do that is to use a standard power transformer, hooking it up "backwards" with the normal secondary connected to the wall wart and the primary connected to the rest of the supply (Fig. 5).

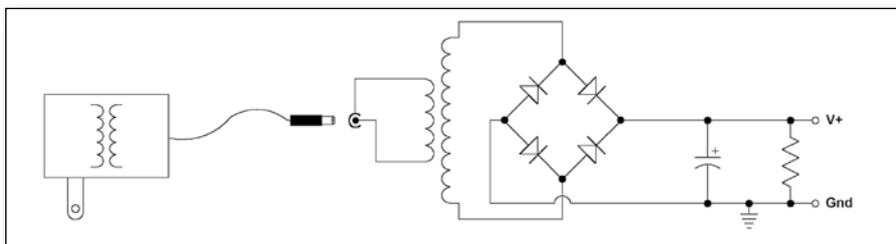


FIGURE 5: Using a second transformer to step up the voltage of a wall wart.

Allied Electronics has a decent variety of power transformers, and the prices of their "house brand" parts are lower than those of many name-brand transformers. Pulling out an Allied catalog, I find that the primaries of most of their transformers are defined as a nominal 117V_{AC} , and $117/3.75 = 31.2\text{V}_{\text{AC}}$. That means that any

Allied power transformer with a nominal secondary voltage of 31.2V_{AC} or lower will step up the wart's voltage adequately. ("Lower?" Yes; a lower nominal secondary voltage means a *greater* turns ratio in the transformer, which means more stepup for the wall wart's voltage.)

In practice, the next-lowest standard transformer voltage is 28V_{AC} ; Allied's cat. # 227-2025 is rated at $28\text{VCT}/1\text{A}$, and costs \$12.53. This has a turns ratio of $117:28$, or about $4.18:1$. Turned backwards, that will step up the 12V_{AC} wall wart's voltage to 50V_{AC} , higher than you need, but it's easy to drop the excess voltage in the filter section. Leave the center tap unconnected.

What about current? An ideal transformer steps down the current when it steps up the voltage, and vice versa. I specified that the phantom power circuit will draw 30mA ; it's easiest to see what happens to the current requirements by thinking backwards. The 117V_{AC} side of the Allied transformer is pulling 30mA , or $.030\text{A}$; the other side is rated at 28V_{AC} , a lower voltage, so the current must be higher by the same ratio, $117:28$, or $4.18\times$. That works out to $4.18 \times .030\text{A} = .125\text{A}$. That's how much current will be passing through the Allied transformer's 28V winding, and because it's rated for 1A there's plenty of margin. Similarly, the wall wart is rated at 1.5A , so it's nowhere near its limits.

Wait a minute, though. This design already has two filament supplies, each drawing 1.2A from warts rated for 1.5A . Would it be possible to piggyback the

Allied transformer onto the first filament supply (with common grounded)? Yes; total draw would then be 1.325A , still within the wall wart's rated capacity. This means you'll have gotten three supplies out of only two wall warts.

How about adding the phantom supply to the balanced-rail \pm supply described

earlier? That has 18V_{AC} wall warts, so the in-the-box transformer needs to have a ratio of $18:45$, or $1:2.5$. This suggests a transformer with a secondary voltage of $117/2.5 = 46.8\text{V}_{\text{AC}}$ or lower, again connected backwards (the 117V_{AC} primary connects to the diode bridge, the secondary to the wall wart).

Flipping through the Allied catalog, I find that none of their house-brand transformers will do the job, but the Triad FP88-65 (Allied cat. # 967-8240) is rated at 44V_{AC} 0.13A with its primaries and secondaries paralleled. The primary is nominally 115V_{AC} , so the turns ratio is $2.6:1$, just about perfect, and it costs \$10.58. It's a "flatpack" transformer, intended for mounting on a circuit board, but a piece of perfboard will work fine.

The internal transformer's output voltage will be $18 \times 2.6 = 47\text{V}_{\text{AC}}$, again a bit high but easy to drop in the filter. Current requirement from the internal transformer will be $.030 \times 2.6 = .078\text{A}$, so it'll pull very little from the wall wart. It would certainly make sense to piggyback this transformer onto one of the wall warts from the \pm supply.

BLUE PLATE SPECIAL

Can you use a wall wart to power a tubed circuit? Yes, but for this you'll need a more drastic step-up transformer.

Say you want a plate supply in the $+250\text{--}300\text{V}_{\text{DC}}$ range that will provide 50mA of current. The easiest way to achieve that is to use a transformer with an "international" primary (dual 120V_{AC} windings). On this type of transformer, the primaries are hooked in parallel for nominal $115\text{--}120\text{V}_{\text{AC}}$ countries, in series for nominal $230\text{--}240\text{V}_{\text{AC}}$.

In this case, choose a transformer with a secondary voltage equal to the wall wart's voltage, and hook it up in reverse. To add a plate supply circuit to the previously described filament/phantom supplies, I'd use another 12V_{AC} wart (to keep Murphy out of the works).

Allied cat. # 227-0102 (\$15.55) has a secondary rated at $12\text{V}_{\text{AC}}/2\text{A}$ and a primary rated at $115/230\text{V}_{\text{AC}}$. Will that be enough juice?

Look at current first. If I draw 50mA ($.05\text{A}$) from the 230V_{AC} primary, I'll be pulling $.05\text{A} \times 230/12 = 0.96\text{A}$ through the 12V_{AC} secondary. This is about half the transformer's rated current, a nice

conservative margin. It'll require a wall wart of its own, though; this is too much to be piggybacking.

What kind of voltage will this provide? Nominally, the supply should produce about $322V_{PK}$, or about $320V_{DC}$ with a $100\mu F$ input cap. With the line voltage 10% below normal, this will drop to about $288V_{DC}$. Allowing a few volts to drop in a second filter stage, regulated $270\text{--}280V_{DC}$ seems reasonable, depending on the dropout voltage of your chosen regulator circuit. When the line voltage goes up to 10% over nominal, expect $353V_{PK}$, or about $350V_{DC}$ on the first filter stage; I'd use filter and bypass capacitors rated for at least $400V_{DC}$.

THREE IN A STACK?

In earlier sections I described methods for piggybacking multiple circuits onto wall warts to obtain three supplies from two warts. Can you get three from *one* wart?

As long as the current draw is reasonable, you can. With commercial parts, there's not enough juice to do filament, plate, and phantom supplies, but (say) $\pm 15V_{DC}$ for op amps and $+48V_{DC}$ for phantom is doable. The part that makes it possible is a transformer with dual primaries and single or dual secondaries of identical voltage. The Hammond 185*230 series is a good example, available from Allied (substitute letters C, D, E, F, or G for the asterisk to choose current rating). Triad makes similar trans-

formers, either in wire-lead or printed-circuit-mounting packages.

Take a look at **Fig. 6**. The two primaries of the top transformer are connected in parallel; the two secondaries are connected in series. The nominal voltages are $115V_{AC}$ and $230V_{AC}$, but in reality this transformer is a general-purpose converter that changes a voltage of X to a voltage of $2X$, with a center tap.

In the example, the Hammond 185F230 transformer (Allied cat. # 836-1881) is connected to an $18V_{AC}$ wall wart to produce a $36V_{CT}$ transformer, perfect for feeding a $\pm 15V_{DC}$ regulated supply. Hanging on the same wart is the Triad FP88-65 to provide phantom power, as discussed above.

How much current can you draw from this supply? The wall wart is rated at 1A; the phantom circuit will pull 0.078A. This means you can draw an additional 922mA from the wart. Because the transformer has an effective 1:2 voltage ratio, the current ratio is the inverse of that, or 1:0.5; you can draw 461mA from the Hammond transformer's secondary. The Hammond transformer is rated at 570mA in series mode, so it will be happy.

Three outputs from one wall wart; what's the catch? Cost—the Hammond transformer runs \$25.26, while an additional wall wart plus chassis jack would cost about \$12.20. The trade-off is paying about \$13 more for the simplicity (and potential Murphy-proofing) of a

single wart. (Note that using the hookup described here also puts a higher-current transformer inside the box, which makes it more likely to cause coupling problems to audio circuits.) Electronics is the art of choice and compromise.

WINDING IT UP

I hope this article has demonstrated that wall warts don't deserve the junky reputation they've attracted. They're actually highly useful gadgets, and can help make your projects easy to build and thoroughly legal. Use them in good health! *ax*

REFERENCES

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2. Paul J. Stamler, "The Gamp: Adaptable Power for Tube Amps," 7/2007 *audioXpress*, p. 20.

SUPPLIERS

Allied Electronics: www.alliedelec.com
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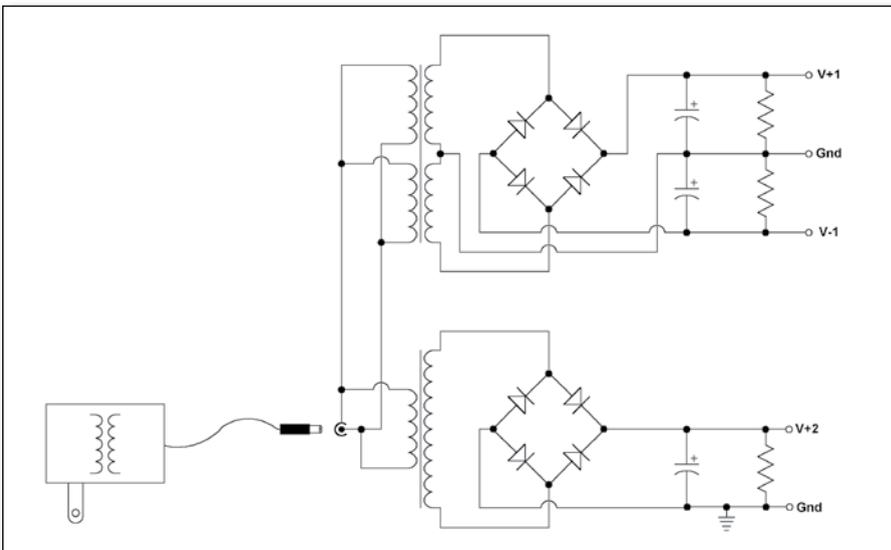


FIGURE 6: Using two additional transformers to derive three DC voltages from a single wall wart.