# OP AMPS FOR AUDIO

# IC Regulated Power

by WALT JUNG

## PART III: Op Amps for Regulator Circuits

WITH THE BASICS of op amp workings behind us in the previous installments, this session introduces a few circuits which (at last, you're probably saying!) put them to work for us. Before jumping directly into involved audio circuitry featuring op amps, I thought it would be a good idea to examine a few exemplary circuits using them in voltage regulators.

All op amp circuits need power, and many audio circuits can effectively utilize smooth, ripple-free power like the kind you get from batteries. If you've ever had problems getting that ripple down to the last fraction of a millivolt to knock out the hum, you'll know what I mean. We've probably all at one time or another wished for a farad of capacity or so to completely kill hum problems. If you can count this sort of thing among your experiences, you'll find the following "electronic" means of hum reduction and voltage regulation interesting, and I hope useful.

First we'll look at the concept and how well it works (and why), and then we'll go into details of how best to apply this knowledge in a general purpose regulator circuit which will be useful to you for years to come. In fact, you'll probably find that once you've used this circuit, you'll never use another type of regulator--it's that good and, to boot, simple and inexpensive!

### A Review of Power Supply Basics

To aid in the understanding of this technique, suppose we digress for a moment or two and review what a power supply filter or regulator is supposed to do. Basically, they fulfill three important functions: filtering, decoupling, and regulation. Filtering a power supply line feeding an amplifier stage removes the AC (called ripple), which usually consists of 60 or 120Hz line frequency components. The main rectifier filter capacitors might show a ripple of as much as a few volts. This is often more than a preamp stage can stand, so filtering is called for.

Stage decoupling is necessary to reduce their interaction due to cross feeding of signal currents via the common power supply. This can cause either oscillations or crosstalk, which of course are both undesirable.

Regulation of a power supply line actually achieves both of the above, and is a most effective means of improving power supply performance. By regulation, we mean the automatic stabilization of a supply line at a fixed potential, i.e., +15V, +20V, or their opposite negative potentials. Regulation holds the supply line to within close limits about the nominal design voltage as either load currents change, or the unregulated DC input changes in accordance with AC input fluctuations.

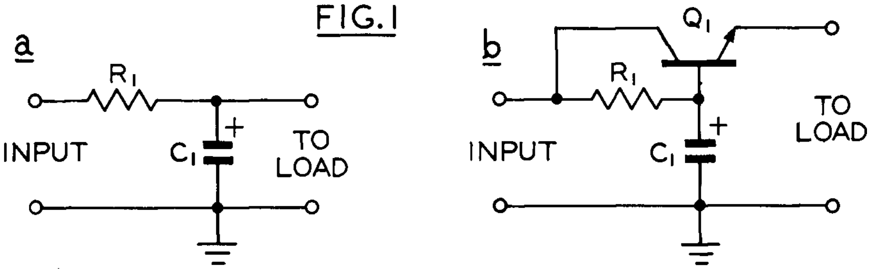
Regulation also accomplishes filtering, and decouples the various loads on the line from one another so they do not interact. And of course, with a regulated DC supply buss having defined limits of voltage, amplifier stages are much easier to design, and are capable of higher performance. From this we can see that schemes to accomplish voltage regulation could be of potential value to good audio circuits (which they are), so let's examine a few.

### Some Simple Power Supply Filter and Regulation Schemes

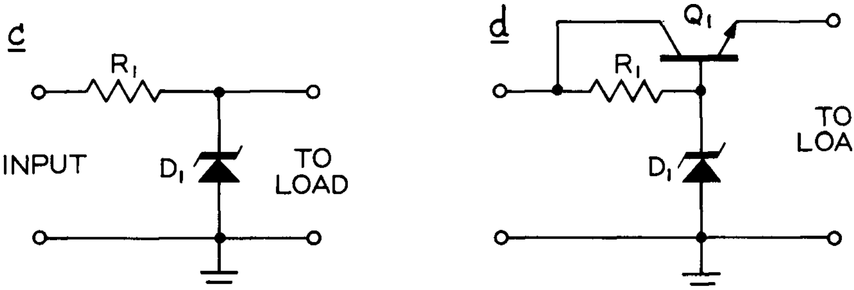
Fig.1a is the most basic form of filter circuit, and is used to reduce output ripple by virtue of the low pass filter formed by R1 and C1. It is limited in performance to relatively low current stages by the practical values for R1 and C1. Since R1 drops DC voltage proportional to the current taken by the load, it usually must be low; however, this forces C1 to be large for good filtering, so consequently it must be an electrolytic type which is large (and can be expensive).

The Fig.1b circuit improves on the simple RC filter by adding a buffer transistor, Q1, which carries the load current. R1 carries only the base current for Q1 which is 100 or more times smaller (how many times is set by the beta of Q1), so R1 can be larger without causing excessive DC drop, and yet give good filtering action. It is possible to get ripple reductions of 40dB or more with this scheme

FIG.1



*a: Simple RC filter* *b: Buffered RC filter*



*c: Simple zener diode regulator* *d: Buffered zener diode regulator*

*Fig.1: Basic power supply filtering and regulation schemes.*

while only dropping a few volts of DC across Q1, so it is a useful trick when you need a small high performance filter. The examples show filter positive voltages; negative supply lines can be accommodated by reversing C1, and substituting a PNP for Q1.

Neither of these circuits accomplishes regulation; for this we must turn to the circuits of 1c and 1d. Fig.1c is a simple shunt zener diode regulator. The zener diode D1 is chosen for the voltage which is desired across the load, and the input voltage must always be higher than the load voltage. R1 is chosen so it can pass the load current, plus the current in the zener. This circuit does regulate the voltage across the load, as the zener diode acts as a low shunt impedance. It also accomplishes filtering of the input signal, as the low AC impedance of diode forms an AC voltage divider with R1 to reduce ripple. It is limited, however, to relatively low load currents and/or source voltages which do not vary excessively.

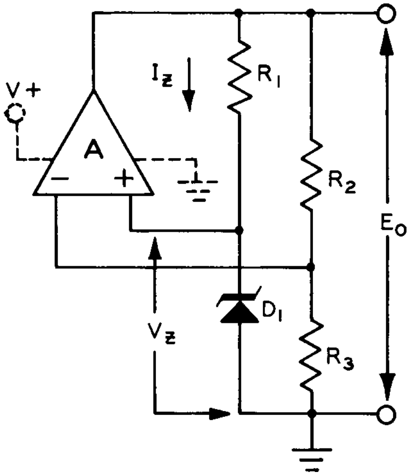
Fig.1d is an improved zener regulator which adds a buffer, Q1. Q1 passes the load current, while the zener in this case acts as a voltage reference for the base of Q1. The output voltage is simply the zener voltage minus the 0.6V of Q1. This circuit is the most effective overall of the four, as it accomplishes reasonable filtering and regulation with relative simplicity. Again, both of these circuits can be transformed to negative use by reversing D1 and using a PNP for Q1.

## Further Regulation Improvements

What has been illustrated thus far is certainly useful circuitry, but it does have its limitations. To go further in the way of improvements, we must add additional circuitry. By so doing we will be able to reduce voltage changes due to regulation at the output to the microvolt region, and provide DC output stabilities of a few millivolts (or less, with judicious parts selection).

First, to appreciate what our soon-to-be-introduced "super" regulator will do for us, we need to examine the weak points of the circuits seen thus far. In general 1d is the best, but it has limitations. Since all zener diodes have a finite regulation impedance, the circuit will still respond to some degree to input changes; either DC shifts or the ripple component. For instance, if you were to use an IN754 for D1, it has a dynamic impedance of 10 Ohms or less. If R1 is 1K, this will only reduce input variations by a 100/1 factor, or 40dB.

FIG.2a



$$I_Z = \frac{E_O - V_Z}{R_1}$$

$$E_O = V_Z \frac{R_2 + R_3}{R_3}$$

*a: Viewed as a bridge*

This variation is seen at the output of Q1, since it operates as an emitter follower. R1 cannot be arbitrarily increased in value to give greater attenuation, since it must also supply base current for Q1. You can make Q1 a high beta type, such as the MPS-U45 or MPS-U95--this helps greatly. However, if you want to change output voltage you must use another zener voltage which moves away from the IN754's minimum impedance, so ripple will increase somewhat.

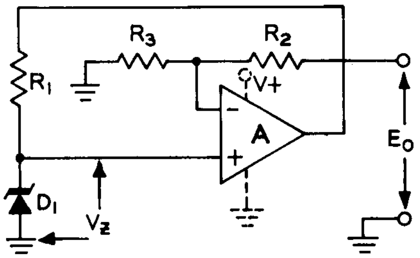
The output from Q1, although regulated to a degree, will vary with loading because of Q1's dynamic emitter resistance. This limits the degree of decoupling Q1 can provide. Also, Q1 is not short-circuit protected (a *must* for experimental work), and a direct short across the load will wipe it out. This failure mode can be eliminated by adding some series resistance in the collector of Q1.

If you sit down and work these points out you can certainly come up with a workable circuit based on 1d for a given output voltage. But let's now take a look at what some active gain can do for us when optimally applied.

## The Op Amp Voltage Regulator

First of all, some of you may already be familiar with the integral IC regulators, such as the LM109/309, the 723 and others. These units have their place, but the technique under discussion here goes beyond any of them in performance capability. So, their exclusion is not an oversight. What we are now talking about goes further.

FIG.2b



$$E_O = V_Z \frac{R_2 + R_3}{R_3}$$

*2b: As a conventional non-inverting DC amplifier*

*Fig.2: Basic op amp voltage regulator.*

OK now, suppose we examine the circuit of Fig.2, called a basic op amp voltage regulator. Here we have a zener diode D1, which is connected in a bridge arrangement with R1-R3 and the op amp. A process of intuitive deduction reveals some very interesting properties of this circuit.

First, assume some positive output voltage Eo. If Eo is greater than the diode's zener voltage, the diode will break down at a voltage, Vz. This establishes a reference voltage at the op amp's (+) input of Vz volts. This stage is actually a DC amplifier which will amplify the input voltage Vz by the factor of $\frac{R2+R3}{R3}$ (the gain factor of a non-inverting stage). This may be more obvious from 2b, which is the same circuit drawn in more conventional form.

The circuit's virtues are: due to zero differential input voltage to A, the circuit scales the zener voltage precisely by the ratio of $\frac{R2+R3}{R3}$. Further, since the zener diode is not loaded by the non-inverting input, no change occurs in Vz due to load current--the *op amp* supplies the load current.

However, the overwhelmingly important asset of this circuit is its almost total immunity to variations in the unregulated input, either DC or AC. This is due to the power supply and common mode rejection figures of the op amp, as the zener is being fed from the op amp *output* rather than the unregulated input (as in 1c or 1d). The zener is in fact "bootstrapped," i.e. it regulates its own current as well as the output voltage.

You can note that the current in the zener (Iz) is proportional to the difference in output and zener voltages, and inversely proportional to the value of R1. Both Vz and Eo are regulated voltages, therefore the current Iz is regulated also, a factor which contributes greatly to the stability.

In case you suspect a "something for nothing" situation, let me calm your fears. As may be most obvious from Fig.2b, the circuit depends on both positive and negative feedback for its operation, to the (+) and (-) inputs respectively. "Aha," you say, "it's unstable!" No, I say, not if constructed properly. The only really potential downfall to stability is at startup.

At switch on, Eo is low and D1 has not yet zenered, so it appears as an open circuit. Under this condition we have more positive feedback than negative, so the amplifier will begin to snap to its output voltage saturation limit. As it goes positive, D1 will soon conduct, establishing Vz at the amplifier's (+) input. With D1 conducting, the positive feedback is reduced to a level less than the negative, thus the negative feedback dominates, and equilibrium is established whereby Vz is scaled up at the output, regulating Eo (and Iz), and a condition of general happiness exists.

The only qualification in the process of arriving at this stage of electronic bliss is in fooling the op amp into never attempting to go negative at switch on, which is decidedly backwards from proper behavior. To insure this, the op amp is operated in a single supply mode so that it cannot reach the undesired stage. Note the dotted V+ and V- (ground) connections to A. As shown the loop will regulate positive outputs at Eo, but negative outputs are also possible by reversing D1, connecting the op amp V+ to common, and the unregulated input to the V- pin.

Although capable of truly excellent performance, the circuit is quite moderate in complexity as Fig.2 shows. Exactly what type of output performance you desire from it will determine the additional complexity and number of components ultimately used.

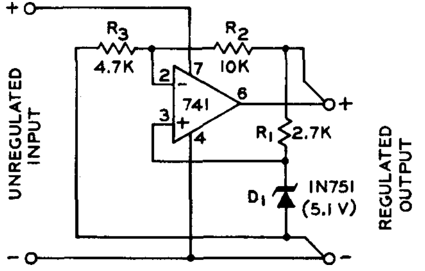
For instance, if you only need a few mA of output current, but the voltage must be razor clean, you can get away with a simple version such as 3a or 3b. Here a 741 is used as the control amplifier and a standard IN751 as the zener. R2 and R3 scale the nominal output to 15 volts, and R1 sets the diode current to 3.67 mA. Output current capability of the circuit is modest (a few mA), since nearly 5mA is used up in driving the bridge, but it should be good for another 5mA. The op amp gives built-in short circuit protection, of course, so it is foolproof as well as clean.

Exactly how good the circuit is in terms of regulation is very difficult to measure, but I have seen input rejection figures of over 100dB with this circuit. If you assume a 1 volt p-p input ripple this equates to 10µV of output ripple! Normally the zener will generate more noise than this, so numbers like 100dB of ripple reduction are really academic. For all practical purposes, as long as the input is above the threshold required to establish regulation, the output voltage is independent of the input. Load regulation is just as difficult to measure; what it amounts to is that the voltage change under load will be controlled by how well you control the voltage drops between the load and where the amplifier actually measures its input. If you measure the output right at the bridge input terminals (the arrow terminals of 3a and 3b), this is the sense point.

No load to full load change for a regulator of this type should be *well below a millivolt* when it is operating properly. To attain this you must keep the heavy current-carrying paths separate from the voltage-sensing bridge, hence the schematic indicates this point. For most audio applications, this type of performance can be considered well nigh perfect.

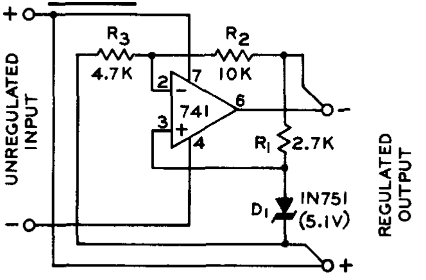
Certain areas within the circuit require attention for best DC stability: namely the diode used. However, for most audio applications absolute DC accuracy and stability are not nearly as important as the inherent good regulation. The circuit's DC stability is only as good as the diode used; if it drifts, the output drifts in proportion.

**FIG.3a**



*3a: Positive output voltage (negative common)*

**FIG.3b**



*3b: Negative output voltage (positive common)*

And when a low drift diode is used for D1, it must also be accompanied by stable resistor types for R2-R3. R1 has a second order effect on output stability, hence it is not as critical to stability as R2-R3.

The values shown are nominal, and should you choose to duplicate this circuit you can feel free to experiment. Since an IN751 is only a ±10% tolerance unit, the output could be expected to vary this much due to the zener voltage alone. If you want to trim it to 15V on the nose, you can select R2 or R3 for a calibrated output. Other zener voltages from 3V or so upwards will work also, but the zener voltage obviously must always be less than the desired output.

Restrictions on the op amp's selection are also very few. It must be compensated for unity gain, and must have a maximum supply voltage rating greater than the highest unregulated DC input. For a 741C or 301A, this is 36V. If you need higher voltage you could use a 1436C, which has a 60V rating, and is a pin for pin substitute for a 741.

## Extending the Regulator's Capability

To extend the capability of this circuit to a general purpose bench supply, we need to add some new components and make a few minor changes which add to its usefulness. The first change is to increase the output current capacity, with (desirably) little increase in cost or complexity. Second, we need to find a means to interconnect two circuits to provide a basic source of ±15V power.

The first step is illustrated in Fig.4, a high performance positive regulator with a +15V, 1.5A output. You'll note this circuit is very similar to 3a, but with the addition of Q1 as a buffer. However, Q1 is more than a simple NPN transistor, even of the power variety. The LM395 is a *monolithic* power transistor, with a current gain of about 1 million (yes, million!) and a 36V, 2A rating.

Further, it has built-in load line limiting and thermal overload protection. Once wired correctly, it is virtually blow-out proof. In short, it is an ideal choice for this application, since it affords automatic overload and thermal protection, and its high current gain insures that the op amp operates with minimum loading. Thus, with the addition of one component we have increased the capability of the circuit manyfold, with a minimum of additional complexity.

The op amp used is a 301A, which necessitates C2, a small value compensation cap. The 101/301 op amp types have the unique capability of being able to operate with their inputs at the same potential as the V+ line, a factor necessary for the next circuit. Thus, a pair of them

*Continued on page 19*

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Table 1
Regulator Performance

A. Positive Regulator (Fig.4)
  Output Voltage: +15V ±5%, ±R2-R3 tolerance
  Output Current: 1.5A
  Input (line) Regulation: 20μV/V
  Output (load) Regulation: <200μV change, no load to 1.5A load
  Output Noise: 1mV p-p wideband without reference filter, <200μV p-p with filter
  Minimum Input-Output Differential: 2V with 1.5A load, lower with lesser currents
  Maximum Unregulated Input Voltage: +36V

B. Negative Regulator (Fig.5)
  Output Voltage: -(Positive output) ±R2-R3 tolerance
  Output Current: 1.5A typical
  Input (line) Regulation: 100μV/V
  Output (load) Regulation: <200μV change, no load to 1.5A load
  Output Noise: essentially the same as noise on positive output
  Minimum Input-Output Differential: 2V with 1.5A load, lower with lesser currents
  Maximum Unregulated Input Voltage: -36V

Protection (both Regulators): short circuit current limited to 2A, load line and thermal protection full time for pass transistors

AUTHOR'S POSTSCRIPT: Table 1 lists typical performance capability of the REF I circuit, but some comments are in order as to what you should expect.

I noticed some variation in noise of the regulator (78L05) from sample to sample. The numbers given were originally based on observed performance using an LM309H unit, which is quieter. Either type will plug in, so take your choice (the kit has LM78L05's).

Ripple rejection in the negative side is dependent upon the value of capacitor used for C6 in B1. This was originally 330pF because of anticipated stability problems, but the prototype card worked fine with 33pF (à la A1), which gives better 120Hz rejection. The figure of 100μV/V (80dB) is really a DC spec, so I wanted to qualify this parameter for you, as it will be somewhat worse at 120Hz.

I'll be interested in reader experiences with this circuit and welcome your comments.

FIG.4

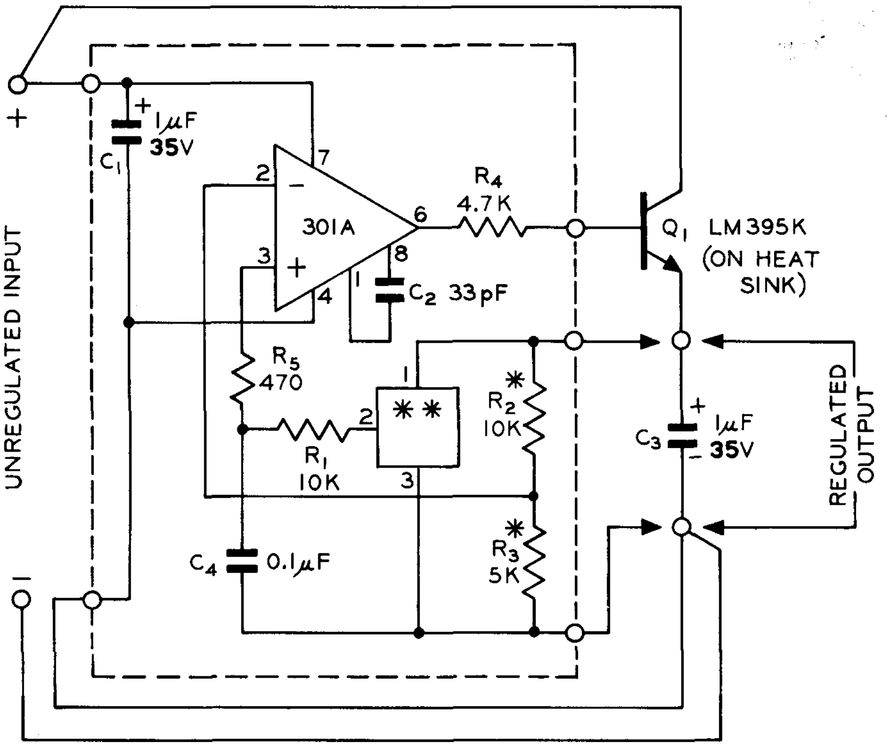
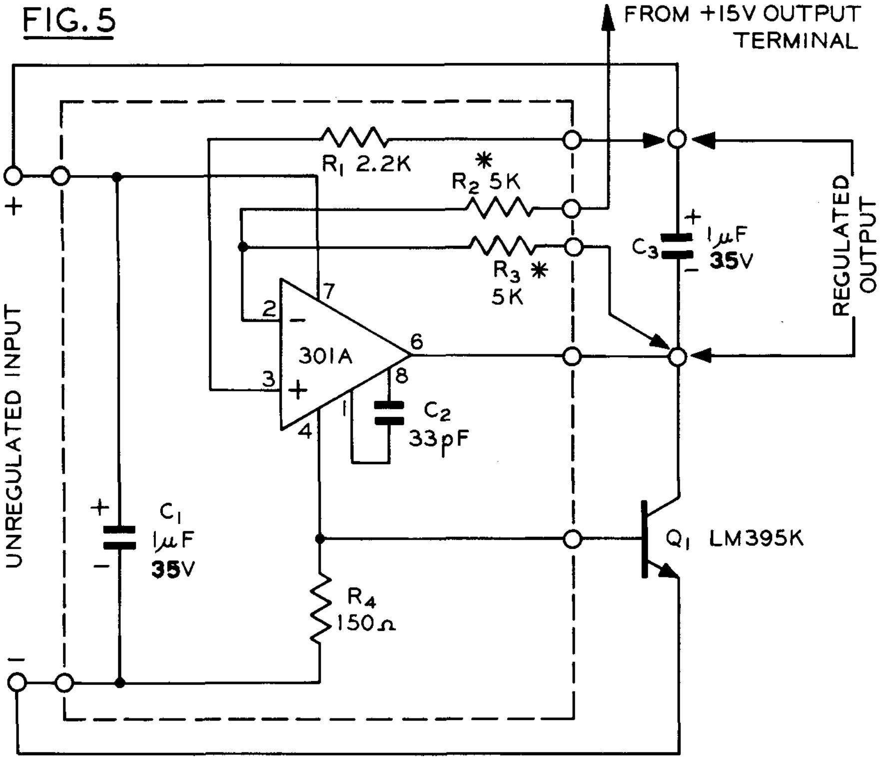


*Fig.4: A high performance +15V, 1.5A regulator*

* For best accuracy and stability use 1% wirewound or metal film types if available

**5V ±4% three terminal regulator: National LM309H or LM78L05AC

FIG.5



* For best accuracy and stability use 1% wirewound or metal film types

*Fig.5: A high performance -15V, 1.5A regulator*

# Constructing One

TO BUILD THE CONTROL CIRCUITS which are illustrated in block form in Fig.6, Old Colony Sound Lab is offering the REF I card, which contains the circuits of Figs.4 and 5 combined, along with the power rectifiers. The actual circuitry and input-output connections of this card are shown in Fig.B1. This is, of course, electrically identical to Figs.4 and 5, but arranged for maximum flexibility and convenience.

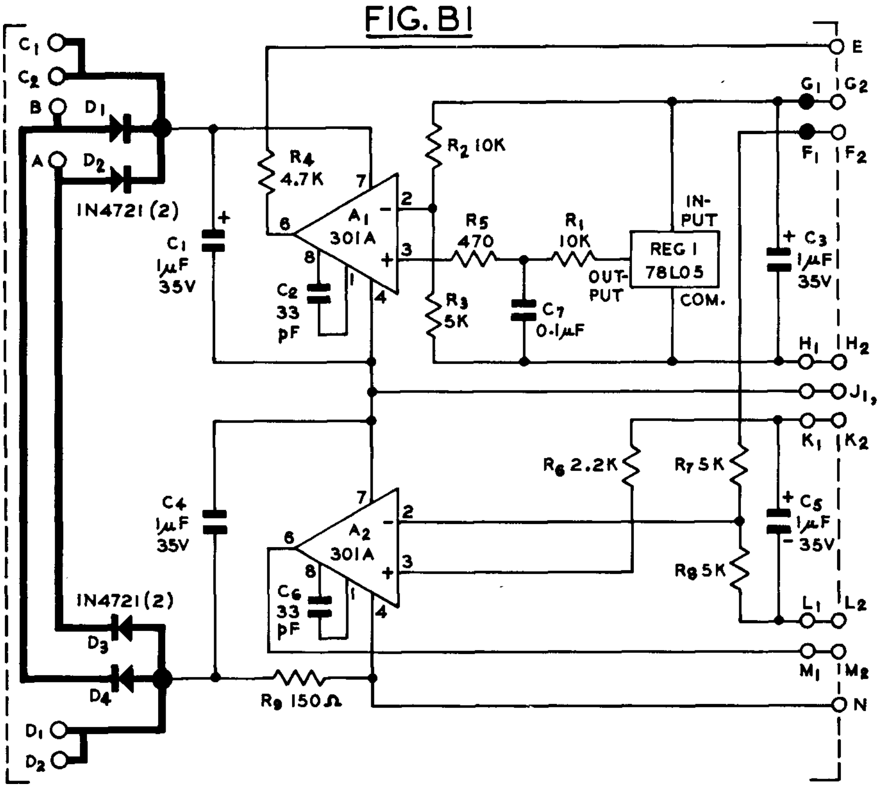
For best results, the parts listed are recommended, and are supplied in the kit. These will yield performance at least equal to that indicated in Table I. Component placement on the card is as indicated in Fig.B2. Note that you are to add two small jumpers as well as the main body of parts. Input-output connections are at hole locations A, B, C1, C2, &c., denoted by a circle with the pertinent designation *within* it. Capacitor locations C1 and C3-C5 are marked with their designations *outside* the circle, and in addition have polarity symbols (so as to avoid confusion with wire locations). All possible wire locations are not used in the ±15V regulator circuit of Fig.6, just those noted by exit wires in Fig.B2.

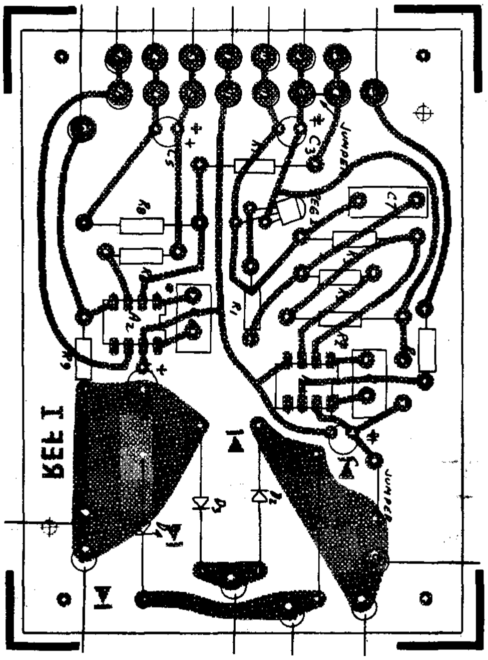
In wiring the card into the circuit, use #18 (or larger) gauge wire for the high current legs. These are noted in Fig.6 as bold lines. The two LM395K's should be mounted on a 2°C/W or less thermal resistance heat sink, such as a Wakefield 641 using thermal grease and TO-3 insulating washers. The mounting holes for the REF I card are laid out to bolt directly to a 641 heat sink, making a neat and compact regulator assembly.

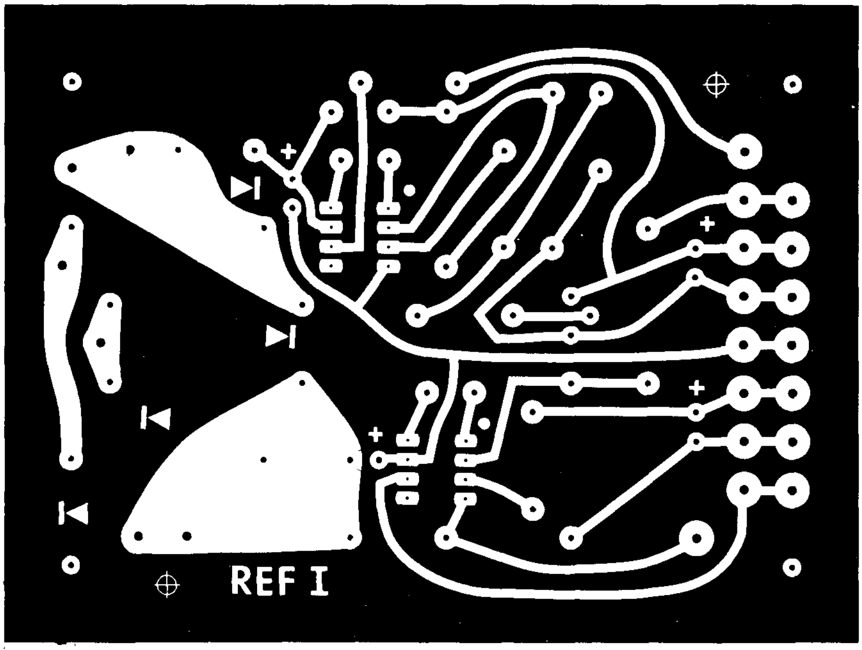
Checkout:

To prevent any possible difficulties at turn-on, you will be wise to apply power to REF I for the first time with the LM395's out of their sockets (or disconnected). Temporarily short R4, and jumper point E to the +15V output. If all components are installed properly this should yield a +15V (±6%) output with loads of 10mA or less. With the +15V side operating, check

FIG. B1







*Continued from page 17*

is used in these regulators. C1 and C3 are added for stability reasons, with C3 being connected directly across the load terminals.

The sharp-eyed reader will note that the reference diode and its feeder resistor, as seen in Fig.3, have been replaced in this circuit. What we now have is an integral 3 terminal regulator (one of the types referred to earlier) which delivers a constant 5V out for any input voltage over 7V. Input is pin 1, and the regulated 5V appears between 2 and 3. These units have their own inherent line regulation; thus, the 5V out is independent of whatever the final output is to be, if other than 15V.

This eliminates the need to adjust a feed resistor for the correct zener current. Further, this type of regulator has a lower self-generated noise than a zener diode, so we're better off in this regard also. As an added bonus, the unit's 5V ±4% guaranteed output also makes the ultimate output very easy to scale.

R1-C4 form a noise filter to reduce the output noise to less than 200µV p-p. Their use is not mandatory, and if you dispense with them (by connecting pin 2 of the regulator directly to the op amps (+) input) you will get only about 1mV p-p of wideband output noise. How-

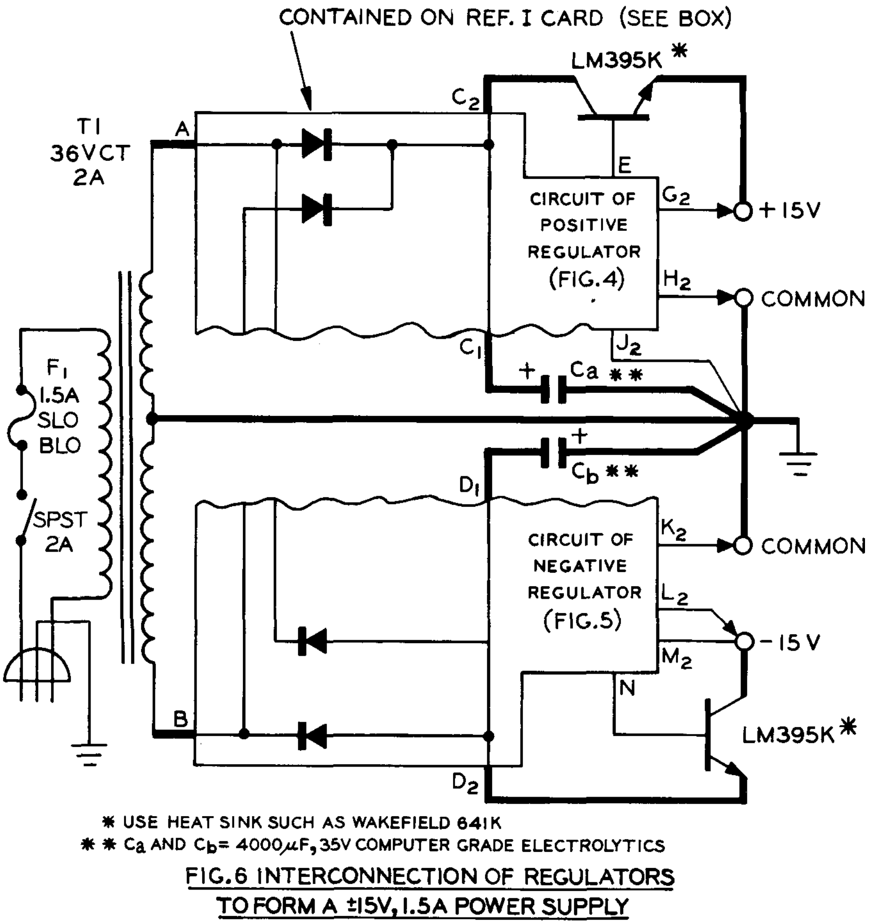


*Fig.6: Interconnection of regulators to form a ±15V, 1.5A power supply*

for -15V also at the -15V output terminal. If *both* of these checks are A-OK, remove power, disconnect jumpers, and install the LM395K's. You now will have a state-of-the-art ±15V, 1.5A power supply.

If you have the necessary equipment to verify the performance, check your unit against the Table I specs, and you should be pleasantly surprised. I will be interested in reader experiences with the REF I card, and if space permits in future months hope to run some alternate configurations possible with this card. We might do a laboratory reference supply, for instance. Good Luck!

PARTS LIST
REF I ±15V REGULATOR CARD

| Reference # | Description/part # | Source |
|---|---|---|
| $A_1$, $A_2$ | LM301AN | National |
| REG 1 | LM78L05ACZ | National |
| $D_1$-$D_4$ | 3A, 200V<br>1N4721 | Motorola |
| $C_1$, $C_3$, $C_4$, $C_5$ | 1µF ±20%, 35V, tantalum<br>TK1-035-105W-20 | Corning |
| $C_2$ | 33pF ±5%, mica<br>DM/CD15ED330J03 | Elmenco |
| $C_7$ | 0.1µF ±10%, 100V<br>C280MAH/A100K | Mepco/Electra<br>(Amperex) |
| $C_6$ | 330pF ±5%, mica<br>DM/CD15FD331J03 | Elmenco |
| $R_1$ | 10K ±10%, ¼W, carbon | Allen Bradley<br>(type "CB") |
| $R_2$ | 10K ±1%, ¼W, film | Allen Bradley<br>(type "CC") |
| $R_3$, $R_7$, $R_8$ | 4.99K ±1%, ¼W, film | Same |
| $R_4$ | 4.7K ±10%, ¼W, carbon | Allen Bradley<br>(type "CB") |
| $R_5$ | 470Ω ±10%, ¼W, carbon | Same |
| $R_6$ | 2.2K ±10%, ¼W, carbon | Same |
| $R_9$ | 150Ω ±10%, ¼W, carbon | Same |

ALTERNATE PARTS FOR REF I KIT

| | | |
|---|---|---|
| $A_1$, $A_2$ | MLM 301AP1 | Motorola |
| $C_1$, $C_3$, $C_4$, $C_5$ | T368A105M035AS<br>196D105X9035HA1<br>B45134, 1µF, 35V | Kemet<br>Sprague<br>Siemens |
| $C_7$ | DMF 1P1-10 | Cornell Dublier |

ever, since we're going for the ultimate supply for audio use, they are a worthy addition.

Again, careful wiring is in order to achieve the full performance of which this circuit is capable. Use heavy (#18) wires to the collector and emitter of Q1, and the (-) unregulated input lead to the (-) or common output terminal. The remaining wires can be ordinary hookup wire.

Fig.5 is a complementary negative regulator, which delivers -15V at 1.5A, with performance comparable to its sister circuit of Fig.4. Unlike the previous circuits, this regulator is not an independent one; rather it obtains a reference from the +15V line.

In reality it consists of a high power inverting amplifier which creates a mirror image of the regulated +15V. Thus it is *slaved* to the +15V, and its output will duplicate the positive voltage on a 1 to 1 basis, but with negative polarity. A 301A is used as the control amplifier, and R2 and R3 are the input and feedback resistors which set up the 1 to 1 ratio. Q1, a second LM395K, is used to handle the heavy output current. Again, it provides the asset of built-in protection with maximum simplicity, and excellent electrical performance.

Ca, Cb, and C3 perform functions similar to those of Fig.4. For best output sensing, R1, R2 and R3 are connected separately, as shown. Heavy current paths are the collector and emitter of Q1, and the (+) unregulated input lead to the (+) common output terminal.

To better understand this circuit's operation, study Fig.6, which shows how they are interconnected. T1 is a fullwave centertapped transformer, supplying AC which is rectified by the bridge D1-D4. Ca and Cb are the filter/storage capacitors for the positive and negative regulators, respectively. A summary of the performance specifications is given in Table 1. If desired, a kit of parts to build the control circuits will be available from Old Colony Sound Lab, as will circuit boards.

## Reference Material for Further Reading

1. Chapter 4 on voltage regulators from *The IC Op Amp Cookbook* by Walter G. Jung (Howard W. Sams & Co., Indianapolis).

On the LM395:

2. "IC with Load Protection Simulates Power Transistor," Robert C. Dobkin, *Electronics,* Feb.7, 1974.
3. "Fast IC Power Transistor with Thermal Protection," Robert C. Dobkin, National Semiconductor AN-110, May 1974.

## AUDIO DEVICES NOTEWORTHY AND NEW

FROM TIME TO TIME, as significant audio IC devices appear, I feel it my obligation to inform *TAA* readers of their presence, comment on their applicability, and indicate how you might best avail yourselves of them. A good example of the value of this is the device featured below, one which represents a new milestone in audio performance. In fact I'll be so bold as to say it will probably become the standard by which other devices of its type will be measured.

I'm referring here to a new monolithic "supermatch" IC transistor pair, National's LM394H. Matched transistor pairs are of course the front end of many linear IC's (such as op amps), and in most cases set the ultimate performance limit for a given device in terms of input parameters. The LM394H, in one fell swoop, improves two significant audio specs by at *least* one order of magnitude with respect to more common devices.

The LM394H has a typical input noise of $1.8nV/\sqrt{Hz}$ at a current of 100µA, a performance level which matches the best discrete transistors. To give you some feel for what this means, an LM394 would generate an equivalent input noise in a 20kHz bandwidth of only 319 nV RMS. In the same bandwidth, a source resistance of 1K generates 709 nV! From this you can see that the LM394's input noise is low in relation to a typical audio source resistance; in this case the resulting noise figure would be less than 1dB.

The LM394 is equally as impressive from the standpoint of its DC parameters. The most outstanding of these is the matching of the pair, in fact a typical LM394 has an emitter base match of 25µV! This means the low end of the dynamic range from both an AC and DC standpoint has been drastically extended. Further, the LM394 retains its matching over a wide dynamic range of voltage and current, and actually its performance very closely approaches the theoretical.

In logging and other transconductance based circuits the LM394 is clearly superior, but its low noise and high gain will also make it attractive as a general purpose audio design tool. Although I have as yet experimented with the LM394 to only a relatively small extent, its improvement over previous dual devices is immediately obvious within a circuit. In the near future I hope to report in more detail on examples of its use in audio circuits. For those interested in the LM394H, small quantity pricing is $4.15, available from National distributors, or you may inquire direct from: National Semiconductor Marketing Services, 2900 Semiconductor Drive, Santa Clara, CA 95051

Two new op amp developments may also be interesting to circuit-minded AA's.

The MC3403 from Motorola is a quad 741 style op amp designed for low power operation from single or dual power supplies. Both inputs and outputs can swing all the way to ground when operated from a single positive supply--a neat trick! This device features the same pinout as the popular 324 type, but the output stage is class AB, designed for low crossover distortion. Price is $4.35 in small quantities from: Motorola Semiconductor Products Inc., P.O. Box 20912, Phoenix, AZ 85036

### WHEN YOU WRITE FOR HELP

1. Please enclose a stamped, self-addressed envelope (S.S.A.E.).
2. Leave room for replies on your sheet of questions.
3. Don't ask for author's addresses. They like their privacy too. We'll forward your letter IF, and only IF, it contains a reply envelope. If the author lives abroad, enclose an addressed, unstamped air mail envelope and one 26¢ international postal reply coupon, available at your post office.
4. Please resist the temptations to use us as design consultants, research assistants, product index clerks, project troubleshooters, or Hi-fi equipment evaluators. Slows up our editing.
5. If you have problems with one of TAA's circuits, fully describe the problem, what you've done about it and include all significant voltage and/or current readings. And don't forget that SSAE.

RCA has introduced a neat little gem in their CA3130, a single, *FET input* op amp. The CA3130 also operates from single power supplies with a "zero volt" input capability, but with the unique feature that its output can swing to either rail. This latter point is due to a *CMOS* output stage, which can also handle 20mA. It's an externally compensated type with a 15mHz bandwidth, and 10V/µs slew rate--useful for many applications, and priced at $1.39 each from: RCA Solid State, Route 202, Somerville, NJ 08876