POWER SUPPLIES

using the uA723

Regulated power supplies can be easy to build if you design them around available IC's. Here are two circuits for low-current low-voltage designs

by WALTER G. JUNG

To some people power supplies are quite unexciting. Others find them intriguing. Regardless of your own personal viewpoint they are a necessary evil, something you must have before power can be applied to any circuit no matter what its type. But with the IC's we'll be discussing here you can build a power supply as good as any home experimenter will ever need. In this initial circuits discussion we'll develop a family of power supplies based mainly on the μA723 regulator. You'll see how to tailor the output voltage to your exact requirements, how to build in the power capability for higher current outputs (up to several amps). How to provide a current limiting feature to protect your experimental projects (as well as the supply itself) and provide multiple output voltages. We'll cover both standard voltages for specific applications and a wide range "general purpose" circuit. The standard circuits you can use over and over on individual projects with the confidence of good performance. The general purpose supply you may want to build as a shop tool for powering circuits in the experimental stage.

The standard voltages these supplies will deliver are +5 volts (for IC logic projects), +12 volts, −12 volts and a symmetrical + and −12 volt supply for op-amp circuitry. We also show you how to build an extended range supply that will put out ±3 to ±15 volts. With this wide range supply you can power any experimental circuit within this voltage range. The negative output is made to track the positive output, so by setting in a value of positive voltage (+6 volts for instance) the negative output automatically becomes equal and opposite. All supplies have current limiting and a standby mode, if desired, allowing temporary shutdown. (The first two circuits are presented this month.)

Let's start off by looking at a basic +12 volt regulator. In Fig. 1 we see the 723 being used to supply a regulated 12 volts at 100 mA. D1, D2 and C1 form a fullwave rectifier, supplying raw unregulated dc to the 723. Since the 723 contains all necessary voltage reference, amplification and series control transistors, a simple two-resistor divider on the output is all we need for a fixed output voltage. The internal reference of the 723 is 7 volts, so for a 12-volt output we need to "scale up" the divider. By using this 12-volt supply as an explanatory example now, you'll see how you can change the output voltage of this basic circuit to suit your own purposes.

The internal control amplifier of the 723 is a differential amplifier. One side of this differential amplifier is fed a reference voltage (in this case the nominal 7.15 volts on pin 3 of the metal-can TO-5 package) and the opposite side senses the output through the divider, this feedback action providing the regulation and control. Since a balanced differential amplifier will have both input bases at very close to the same potential, the tap (R2-R3 junction) on the divider will also be at 7.15 volts. If we set a nominal bleeder current in the divider of about 1 mA, this makes R3 6800 ohms. Then R2 must make up

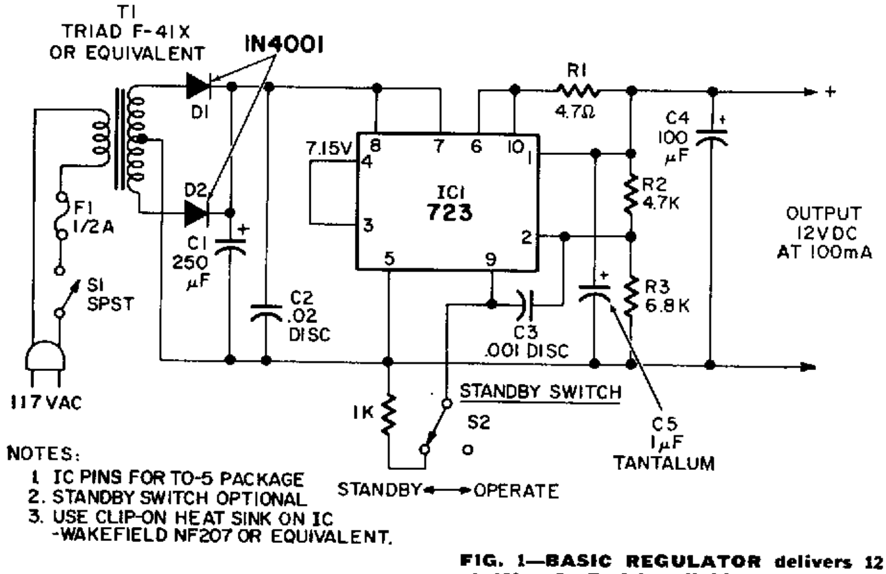


FIG. 1—BASIC REGULATOR delivers 12 at 100 mA. Resistor divider sets output.

the difference for 12 volts, and the voltage across it will be 12−7.15 or 4.85 volts. By Ohm's law, $R2=\frac{4.85}{1.05}=4.7K$ (since 7 volts across 6800 ohms will be slightly more than 1 mA, or 1.05 mA). It's as simple as that—set 1 mA in the divider and select R2 to make up the difference in voltage between the desired voltage and 7 volts. You can set the output to values other than 12 volts by choosing different values of R2 with R3 remaining as 6800 ohms. For instance, if you wanted a 10-volt regulator, the procedure would be as follows:

E across $R2=E_o-7.15$ or $10-7.15=2.85$ volts. Since I=constant of 1.05 mA, $R2=\frac{2.85}{1.05}$ or 2.7K in this case.

If this procedure is not exact enough and you want to set the voltage precisely at some value, insert a 2000-ohm pot between R2 and R3 and feed pin 2 of the 723 from the arm. Then you'll be able to trim out the tolerances of the resistors and the 7-volt reference, and set your output to precisely the desired value.

By either method the output remains stable once set, due to the inherent stability of the IC chip. Use quality resistors for R2 and R3 if possible; well derated, deposited carbon or film types if available.

As for the rest of the circuit, C3 provides internal frequency compensation for the IC's control amplifier. Two more capacitors are used on the output, C4 and C5. C4 is a fat electrolytic to provide energy storage for current peaks and keep the regulator's output impedance low at higher frequencies where the 723's gain falls off. C5 provides more insurance against this high-frequency impedance rise, taking over where the internal inductance of C4 begins to kill its effectiveness. The combination of these capacitors and the load regulation of the IC combine to make truly effective regulation. The remaining capacitor, C2, is a ceramic disc used as a high-frequency bypass on the input lines. This capacitor should be placed directly across the IC's input leads to stop any tendency towards the 723 believing it's an rf oscillator.

The remaining circuit component is R1, the short-circuit limit resistor. Since it is in series with the circuit's output current, it develops a voltage drop proportional to the load drawn at the output. This voltage is used to turn on an internal transistor at a predetermined output current, thus protecting both the IC and the external load. This operation is automatic, and normal operation is restored as soon as the output load is reduced to normal limits. The value shown will current limit at about 150 mA, a reasonable figure for the 723 without a booster stage. When we see some really powerful regulators (1 to 2 amps in future articles) this resistor will reduce proportionately. To calculate a new value of R1 (for a different short-circuit current maximum) the formula is simple. Since the voltage drop across it is 1 V_{be} (about 0.7 volt) it is $R1=\frac{0.7}{I_{max}}$. Should you want to protect this 12-volt circuit at a lower limit, say 70 mA; R1 would be $\frac{0.7}{.07}=10$ ohms. In any case the short-circuit current should be about 25% greater than the maximum load current.

So much for all the talk on what the circuit components do. How well does it work? A regulated 12 volts can be supplied with load regulation better than 0.1%. Line regulation is even better than this, and ripple less than 1-mV peak to peak. The current-limit feature can be used to protect against those inevitable load short circuits very effectively, preventing destruction of valuable components. This circuit will be more than adequately precise to power any positive voltage requirement we will be discussing here; and by using a current booster modification, with up to several amps of output current. To scale the output voltage and for different current limit capability, follow the guidelines given above.

For output voltages *higher* than 12 volts the procedure for R2 selection is exactly the same. The power transformer output voltage must be raised to accommodate the extra voltage, however. The Triad F-41X specified here is fine for regulated outputs *up to* 12 volts. But since the 723 needs about 3 volts minimum difference between its input and the regulated output, the unregulated dc must be high enough to suit this requirement.

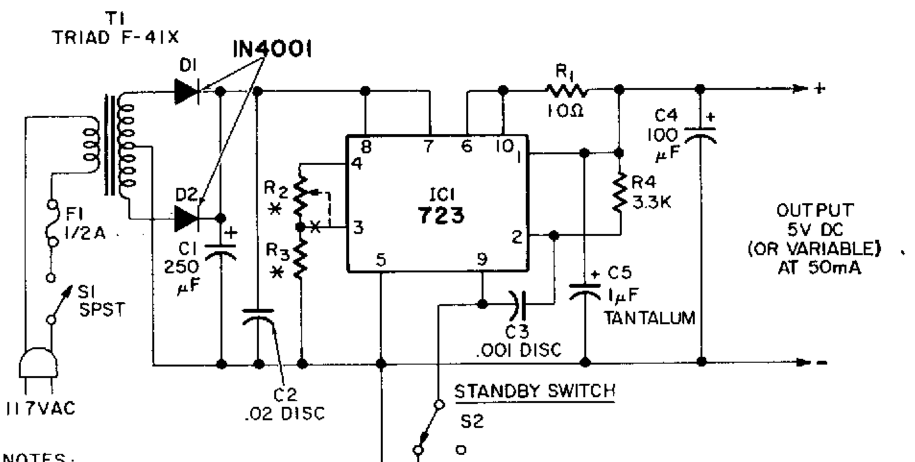
For a 20-volt regulator you need about 23 Vdc minimum at pins 7 and 8 of the IC. And of course, you'll have to up the voltage ratings on the capacitors to suit your higher working voltages. A good choice in flexibility which gets around this dc requirement are the variable tap rectifier transformers which allow you to set the unregulated voltage output closely to what the regulator requires and minimize the power the 723 has to drop in accomplishing its regulation. Remember, the price of regulation is power dissipation and if the voltage drop across the IC gets high enough at substantial load currents it can get hot. Its power dissipation is roughly $(E_{in}-E_{out})\times(I_{out})$, and should be kept below 800 mW for safety's sake and longevity. Later on in the high power regulators we'll see how the IC's dissipation can be effectively reduced to a negligible minimum.

Low-voltage 723 regulator

By now it has probably occurred to the reader that the circuit in Fig. 1 makes no provision for output voltages below the 7-volt reference. But don't give up yet! To do this we use the circuit of Fig. 2, a +5 volt example suitable for powering IC logic devices such as gates and flip-flops. In this version, instead of connecting the 7-volt reference voltage (developed in the IC at pin 4) directly to 3, it is divided down to the desired output level (in this case 5 volts) and *then* applied to pin 3. No divider is used on the output and pin 2 senses the output through isolation resistor R4. Using the 723 in this manner causes the output voltage to exactly duplicate the potential applied to pin 3 from 2 up to the maximum of 7.15 volts (reference voltage). If a fixed 5-volt output is not desired, a variable 2 to 7 volts can be obtained by making R2 and R3 a variable divider.

The lower regulation limit of the IC is 2 volts, and you should not try this circuit below this limit. This arrangement covers all of the most often used lower supply voltages; 3.6 volts, 5 volts and 6 volts.

This makes this regulator hookup quite attractive as a logic power supply, where current demands can very quickly get up into the hundreds of milliamps or even ampere region. To use this circuit as it stands would be inefficient for a large scale project, but it is fine for applications requiring less than 70 mA. The reason behind this limited current drain is one of efficiency, because at the lower output voltages the IC dissipates the bulk of the input power when feeding a load. This is the reason why a clip-on heat sink is recommended. **R-E**



NOTES:
1. IC PINS FOR TO-5 PACKAGE
2. STANDBY SWITCH OPTIONAL
3. USE CLIP-ON HEAT SINK ON IC -WAKEFIELD NF207 OR EQUIVALENT

STANDBY←→OPERATE

*FOR FIXED 5 VOLT OUTPUT R2=2.2K, R3=5.1K. FOR VARIABLE 2-7 VOLT OUTPUT R2=5K POT (CONNECTED AS SHOWN DOTTED) AND R3=2.2K

FIG. 2—VARIABLE OUTPUT VOLTAGE or 5 Vdc is delivered by this circuit.

IC Power Supplies

more uA723 circuits

High-power regulated supplies can also use IC regulators. The secret is to provide "booster" transistors to handle the load

by WALTER G. JUNG

TO GET A HIGH-CURRENT SUPPLY WE turn to Fig 1 a μA723 regulator with a booster stage. The use of external booster transistors removes virtually all restrictions on the IC's power handling capacity, as it now only has to supply a small amount of base current to the booster transistor which handles the bulk of the power dissipated in the regulation process. The beauty of this approach is that it allows us to retain all of the previous good regulation features of the IC control amplifier and yet still handle a much larger current output. A booster stage can be used with either the low or high voltage regulator configurations, and enables either type of regulator to deliver up to 500 mA.

Schematically the circuit is rather simple. A silicon pnp power transistor (Q1, a 2N4918) is connected as shown in Fig. 1 to raise the power capability of this 12-volt circuit to 500 mA. An additional resistor (R_b) is needed from base to emitter of Q1, and the base control current for Q1 is delivered from pin 7

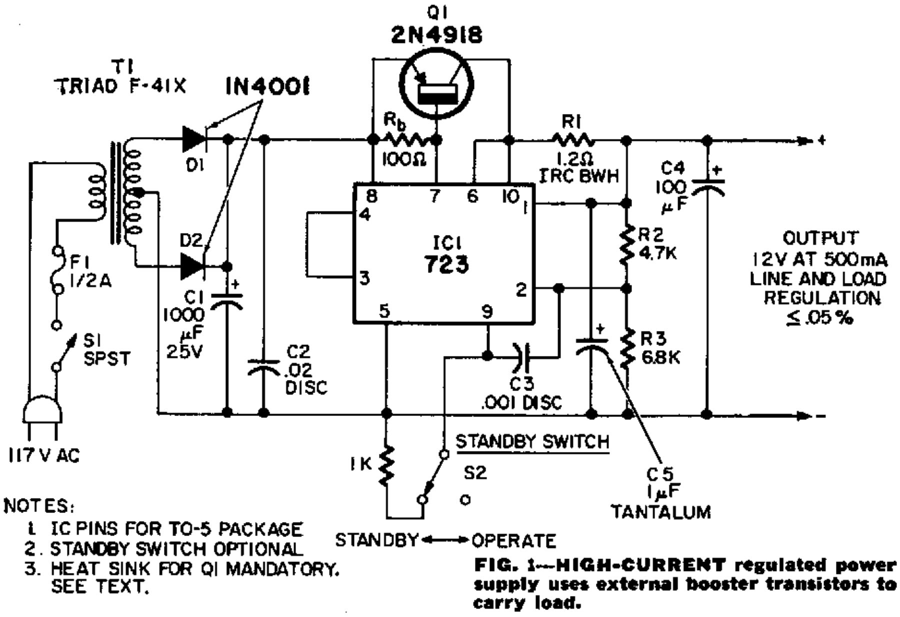


FIG. 1—HIGH-CURRENT regulated power supply uses external booster transistors to carry load.

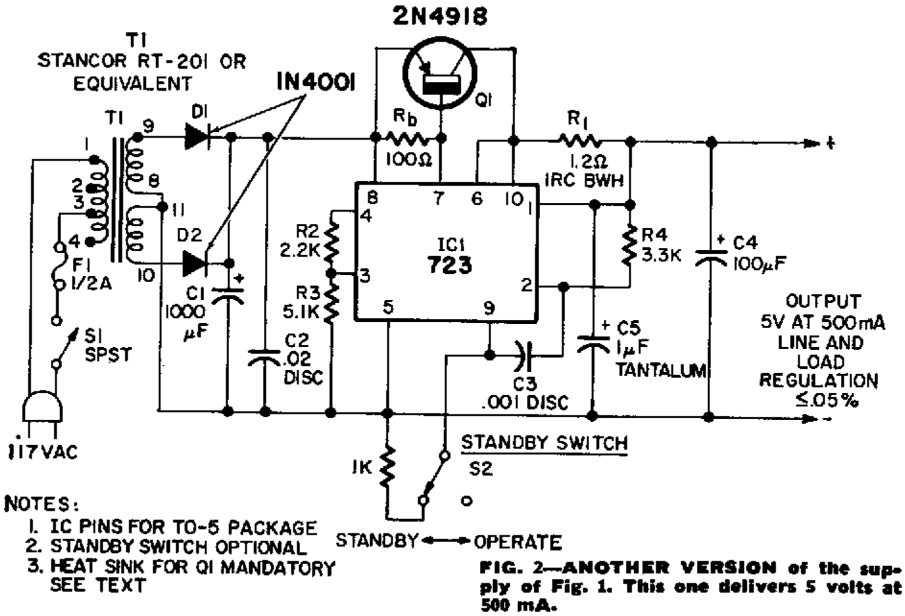


FIG. 2—ANOTHER VERSION of the supply of Fig. 1. This one delivers 5 volts at 500 mA.

of the IC. In this manner the bulk of the output current is handled by Q1 and the IC handles only the smaller base current of Q1. To illustrate what this does for us, let's look at some typical numbers. If we assume a dc current gain of 50 for Q1 at a current of 500 mA, the IC need only provide 10 mA to drive Q1. At lower load currents, even less than this. So we can see how this hookup reduces the strain on the IC, minimizing its temperature rise due to the lower power dissipation.

At 500 mA Q1 definitely needs a heat sink for prolonged operation. Figure 3 shows a simple method of heat removal using the chassis as a sink. Solder Q1's leads to the circuit board and position the metalized face over a chassis mounting hole. Secure the transistor to the chassis with the screw and insulating washer provided and use silicone grease on both sides of the washer.

The same transformer is used in this 12-volt regulator but the input filter is raised to 1000 µF to keep input ripple down with the increased current drain. And the current limiting resistor is lowered to correspond to the increased output current.

Many of the above comments on the 12-volt version apply also to the 5-volt 500-mA regulator shown in Fig. 2. The booster transistor connections and current limit change are the same as for the 12-volt version. The main difference is the substitution of a different power transformer. This permits lowering the input voltage, minimizing the voltages across Q1 and improving efficiency. Q1 of course, should be mounted as before (see Fig. 3).

We can also carry this booster technique one step further and come up with a 2-ampere regulator. To do this we add one more pass transistor, increase the filter capacitance, substitute huskier rectifier diodes, a larger power transformer and lower the current limiting resistor value once more.

A circuit of a 5-volt, 2-amp regulator with the changes mentioned above is Fig 4. The additional booster transistor is Q2, a 2N3055 which is driven in turn by the 2N4918. A complementary Darlington connection is used to minimize voltage drop across the pair. Since Q2 can dissipate quite sizeable power in this application a large heat sink is mandatory. Use the type recommended or one with equivalent performance for best results, and don't skip the silicone grease under the mounting washer.

The short-circuit-current limit resistor is a two-resistor parallel combination because of wattage considerations. A separate rectifier and filter capacitor (D3-C2) is used to supply voltage to the IC. This is done to minimize input ripple feedthru which would otherwise be high due to the ripple across C1 at high current outputs. The extra filtering of C2 (which is isolated from C1's ripple by D3) smoothes the voltage at pin 8 of the IC and minimizes the effects of input ripple on the output.

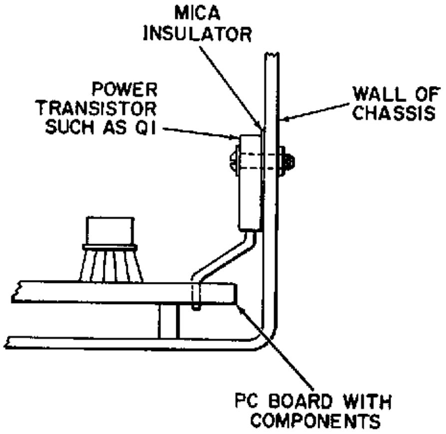


FIG. 3—RECOMMENDED HEAT-SINK arrangement for power transistors in Figs. 1 & 2.

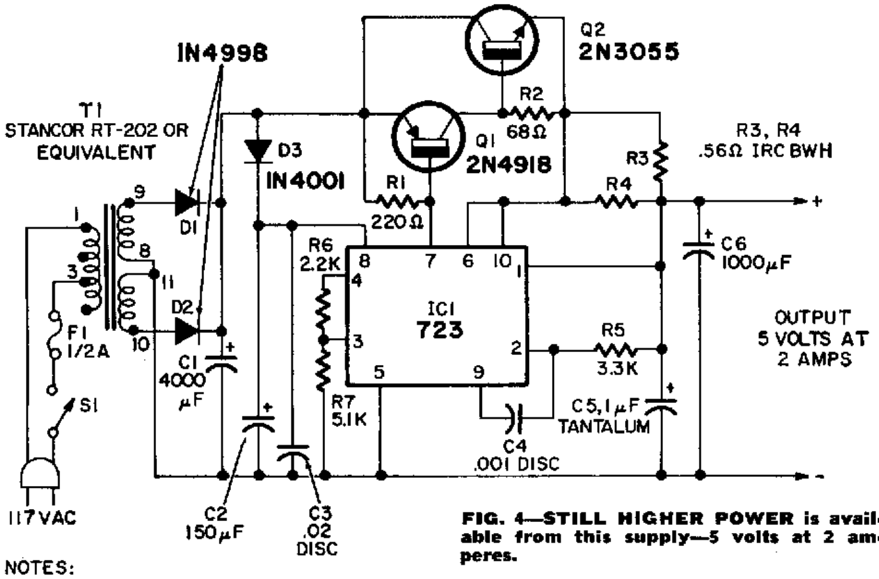
Power supply systems

In this section we'll talk about using the power supplies we've developed thus far in various practical combinations. As we discuss these combinations we will also evolve another type of power supply—the *tracking* supply. This is the final circuit in this section, and the one most suitable for those electronic projects on the experimenter's workbench. We'll go as deeply into this one as possible so you can get the maximum out of it.

By themselves any one of the circuits we've talked about up to now have been entirely usable as they stand. You can pick the voltages and current rating you need and build that supply. But suppose you need two supplies, such as ±12 volts. You could just build 2 supplies (as in Figs. 1 or 3, *Radio-Electronics,* July 1971) and connect the output in series as shown in Fig. 5 and use them as a ±12 volt supply. This would certainly do the job, but there might be a simpler way.

If we review all of the circuits we have talked about so far we can note they have one thing in common. They are all *positive* leg regulators—they regulate the output voltage by a variable resistance in the *positive leg* of the circuit. This is either Q1, Q2 or the IC itself. (see Fig. 6).

The next section in the continuing series of articles will look into negative-leg regulators and will examine regulated power supplies using other IC types. R-E



NOTES:
1. IC PIN NOS. FOR TO-5 PACKAGE
2. HEAT SINK FOR Q2 MANDATORY-WAKEFIELD NC623A OR EQUIVALENT CHASSIS AREA.

FIG. 4—STILL HIGHER POWER is available from this supply—5 volts at 2 amperes.

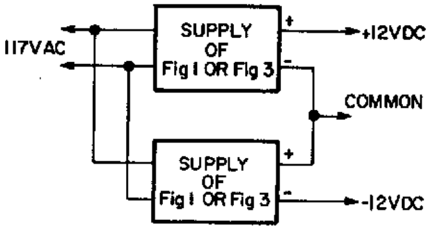
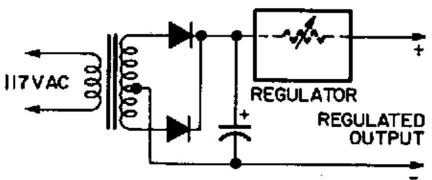


FIG. 5—FOR DUAL SUPPLIES just combine two of the circuits you have built.

FIG. 6—POSITIVE-LEG REGULATORS have been described so far. The regulator is in the positive leg of the supply.



You and your ultrasonic clothes washer!

IC Power Supplies

dual outputs with uA723's

Two more regulated-output supplies. These have dual outputs delivering positive and negative voltages

by WALTER G. JUNG

HERE IS THE FINAL SECTION OF OUR discussion of IC power supplies. It is completely concerned with dual-output supplies. Two circuits you can use are presented.

Now suppose we had a regulator that was the mirror image of our positive regulator. We could regulate negative leg voltages in the same manner as we've done for the positive voltage.

The big advantage to taking this approach is that it allows us to use a single transformer in a center-tapped bridge hookup, thereby saving a complete power transformer in some applications (see Fig. 1). We can make the negative regulator quite simple by slaving its output to the positive supply, forcing it to be equal and opposite. This means the negative output voltage will always be equal and *opposite* to the positive voltage. So by adjusting the positive potential we will be adjusting the negative one also, as it *tracks* the positive.

To see how this is done turn to Fig. 2, a dual (±) 12-volt supply with a 100-mA output from both sides.

In understanding this regulator, it might be well to think a moment of what is desired of this negative voltage supply. We already have a good positive 12-volt supply using the μA723. This is the upper portion, basically the same as Fig. 1, page 49 of the July issue. What we would like is a negative voltage that is the mirror image of this one, or −12 volts.

If we had a dc power amplifier which could supply a lot of current, we could feed it the +12 volts and get out −12 volts, couldn't we, the −12 volts being supplied from an unregulated minus voltage. Well, what we have boils down to just about that. The μA709 IC and pnp emitter follower Q1 form the power amplifier, and the +12-volt line is used as a signal input to the μA709. Recalling our illustration of a feedback amplifier (see **Radio-Electronics**, June, 1971, page 58), we recognize R4 as R_{in} and R5 as R_f. This is an inverting amplifier with a dc gain of −1 as

$$\frac{R_f}{R_{in}} = \frac{10,000}{10,000} = 1$$

It regulates the −12-volt output by exactly reproducing the +12-volt output inverted. The unregulated input changes and ripple appearing across C5 (the negative supply's unregulated input) do not appear on the output because of the degeneration inherent to the IC and the extremely low output impedance provided by the 100% negative feedback.

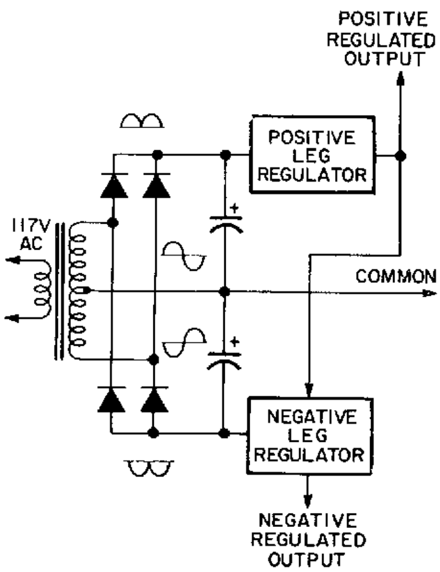
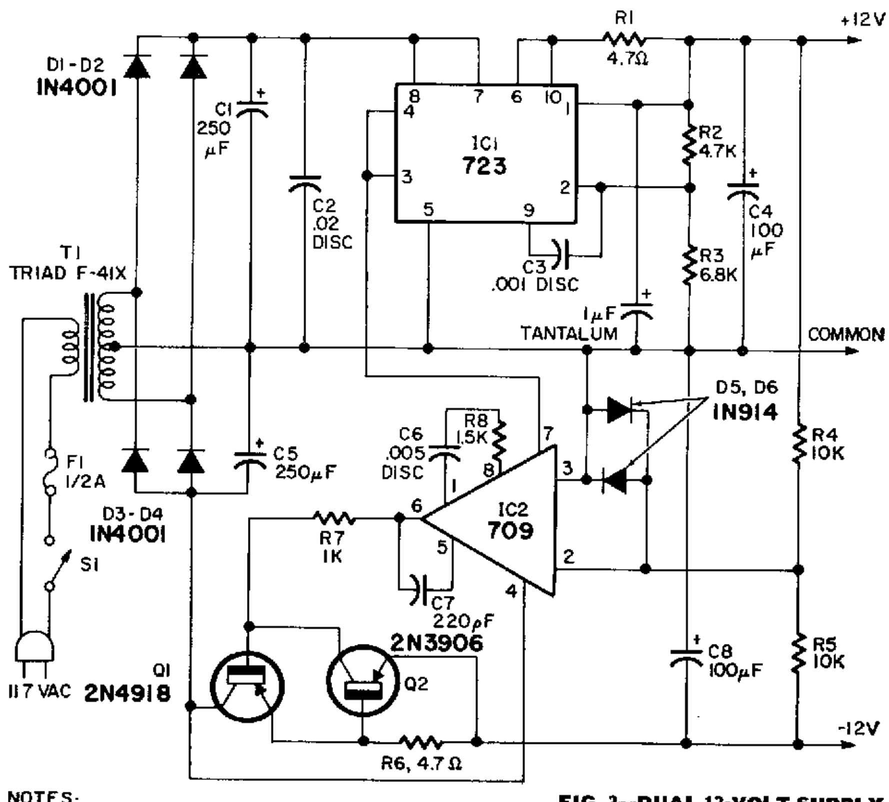


FIG. 1—DUAL-OUTPUT CIRCUITS take advantage of center-tapped power transformers. Both outputs track precisely.



NOTES:
1. PIN NOS. FOR BOTH IC's FOR TO-5 PACKAGE
2. USE CLIP-ON HEAT SINK (NF-207) ON IC1

FIG. 2—DUAL 12-VOLT SUPPLY delivers 100 mA both positive and negative legs.

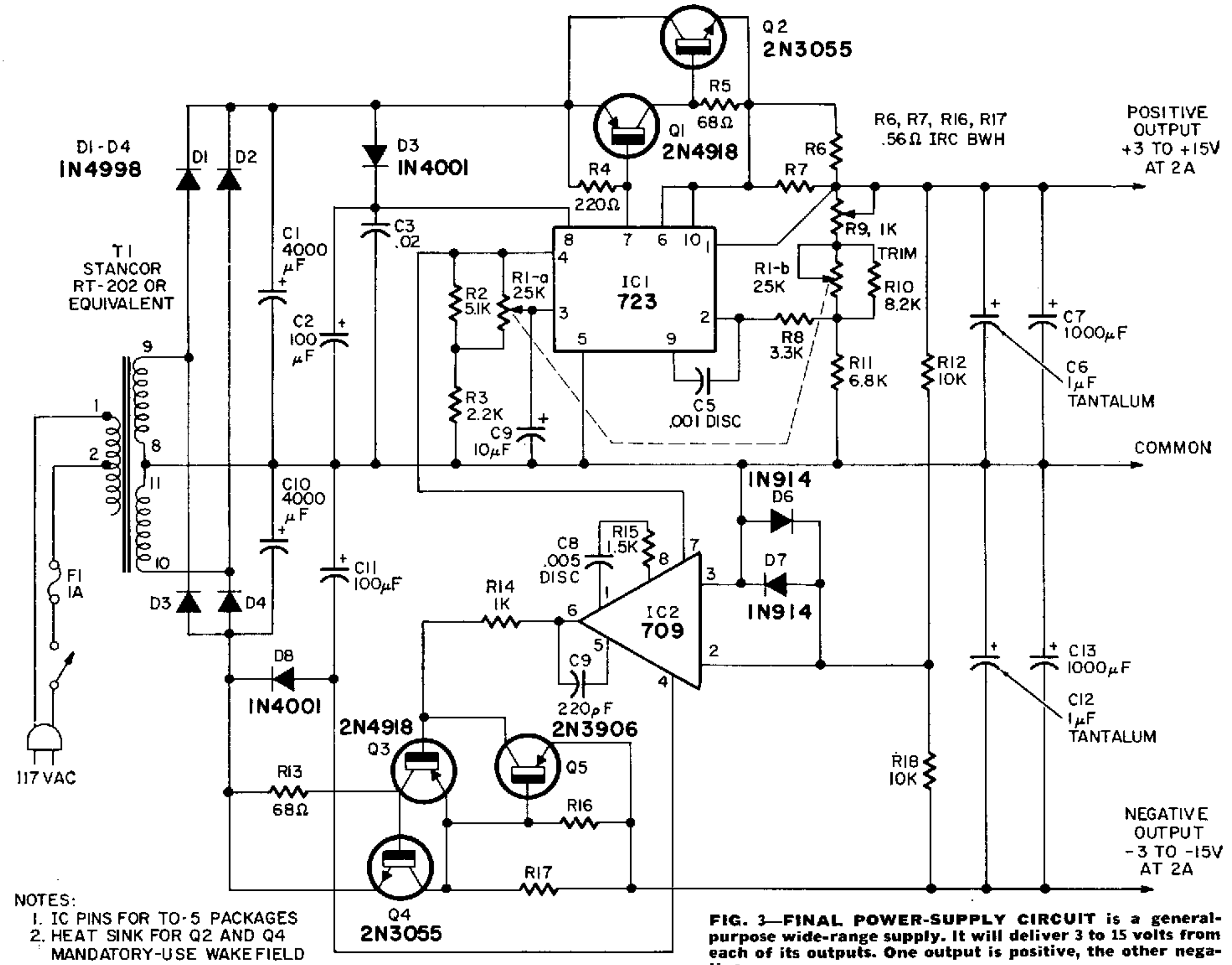


FIG. 3—FINAL POWER-SUPPLY CIRCUIT is a general-purpose wide-range supply. It will deliver 3 to 15 volts from each of its outputs. One output is positive, the other negative.

Since this negative voltage regulator is really an amplifier amplifying whatever it is fed from the positive input, it logically follows that changes in the positive supply will appear equal and inverted on the negative supply. If you adjust the positive output from +12 to +10, the negative will move from −12 to −10, following or "tracking" the positive supply.

Another practical detail of the circuit is current limit transistor Q2—used to bias off the regulator under overload conditions. This transistor works like the scheme used in the μA723. When the output current passing through Q1 becomes higher than a predetermined limit, Q2 turns on and removes bias from Q1, limiting the output current and preventing damage. Additional protection for the input stage of the μA709 is provided by the back to back diodes (D5-D6) across its input terminals which limit excess voltage under overload conditions. The μA709 uses the standard frequency compensation networks (R8,C6,C7).

By using this idea of a tracking complementary regulator we've eliminated many of the components of a second regulator. We've saved a second power transformer and simplified the negative regulator. This particular circuit version (±12 volts 100 mA) is ideal for powering operational amplifiers circuits (using more 709's) which we'll be talking of later on.

As a finale for our power supply discussions on the μA723 IC we'll develop that general-purpose wide-range supply we mentioned earlier. This circuit is basically the same as the dual supply of Fig. 2, but has a variable voltage feature of 3 to 15 volts. In addition the current output of both legs is raised to 2 amperes. Since the voltage variation from 3 to 15 volts is something we have not covered as yet, we'll talk about that feature first, then the supply as a whole.

The schematic of this wide-range general-purpose supply is in Fig. 3, and as before we notice many similarities to the previous circuits. The μA723 upper portion is a 2-amp regulator similar to Fig. 1 in some respects. The main difference is in the voltage determining components. From our earlier circuits we recall that dividing the reference voltage of the μA723 gave us voltages lower than 7.15 volts, and scaling the output divider gave voltages greater than 7.15. But suppose we wanted a range of voltage from below 7.15 volts to well above, could we do this in a single circuit? The answer is yes and Fig. 3 is an example of such a hookup.

This circuit uses a combination of reference voltage division (R1-a–R3) and output scaling (R1-b–R11) to both create a variable reference voltage at pin 3 and scale this voltage up. R1-a and R1-b are a ganged pair of pots connected so that as the resistance of R1-b *increases,* R1-a moves towards pin 4's potential (7.15 volts). Assume for a moment that R1-a is at maximum and pin 3 has the full reference voltage of 7.15 volts on it. Then with the full resistance of R1-b in the circuit the output voltage will be determined just as we calculated in the July issue. It will be the voltage across R1-b + R9 plus the voltage across R3 (7.15 volts). The values of R1-b and R9 are chosen to give 15 volts out with 7.15 volts on pin 3, the maximum output. In addition, the resistance of R9 serves as trim control for fine adjustment.

As the wiper of R1-a moves towards R3, two things happen to lower the output voltage. The voltage at R1-a's arm will be less than 7.15 because of the division. And R1-b will be a smaller resistance also, so these two things lower the output. At the other extreme of rotation R1-b is shorted and R1-a–R3 is at 3 volts, the lower limit of the circuit. With this range of voltage adjustment of the positive regulator, it is easy to make the

(continued on page 94)

IC POWER SUPPLIES
(continued from page 45)

negative side track. This done by making R12 and R18 equal.

The negative portion of the circuit is made up of IC2, Q3, Q4 and Q5. The 2-amp output rating is supplied by Q2 and Q4, a pair of 2N3055's. These two transistors need to be well heat-sinked so follow the recommendations. Other portions of the circuit are beefed up accordingly; a pair of large computer grade input filters (C1-C10), husky rectifiers (D1-D4) and 0.27-ohm current limit resistors in each leg. Extra filtering is on the output too, C7 and C13.

This concludes the 723 "family" of power supplies. **R-E**