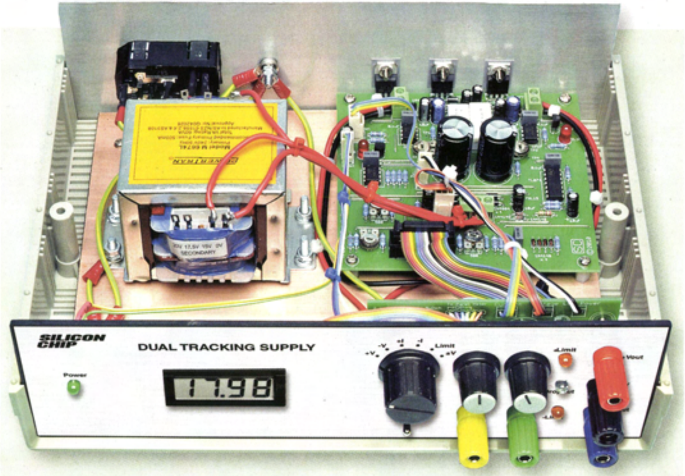


Dual Tracking ±0-19V Power Supply

By NICHOLAS VINEN

This linear bench supply can deliver up to 1.6A from positive and negative outputs with a range of ±0-19V. It has adjustable current limiting for both outputs and can display the voltage or current reading for either rail. If powered from an AC plugpack, no mains wiring is required, although less current is available. It also has a 5V 750mA output for powering digital logic ICs and microcontrollers.

THIS TRACKING bench supply is built almost entirely from standard components but provides high performance. It is a linear supply which offers very good regulation and very low ripple and noise (see specifications table). It also boasts a digital display for voltage and current readouts and this can also show the voltage across both rails or the present current-limit setting.

The primary outputs track each other, providing balanced rails, or a load can be connected across both to double the voltage. Either way, the current limit can be adjusted from 0-1.6A (0-1.0A for the plugpack version). The internal regulators are protected against excessive temperature or current.

A third output supplies a fixed 5.0V at up to 750mA. The supply also incorporates an earth terminal, a load switch (which controls all three outputs) and a power switch.

This supply is particularly well suited for breadboarding, especially for circuits which mix digital logic and analog signal processing. If you prototype this type of circuit often you will be familiar with the hassles involved with building a power supply each time which is able to deliver 5V and/or 3.3V, along with balanced rails (eg, ±15V) for the op amps.

With a tracking supply such as this one, not only is most of that effort spared but you can easily observe the current consumed by the op amps and set the current limit to a suitable level so that a wiring mistake in the prototype will not cause any damage.

We have tried to keep the cost and complexity down as much as possible while providing several improvements over our original Dual Tracking Supply which we featured way back in the January 1988 issue. The improvements include current readout, adjustable current limit, fixed 5V output, digital display, a voltage measurement across both outputs, a larger transformer and the plugpack supply option.

Construction is simplified by mounting most of the front panel components on a second PC board. This is connected to the main PC board via several ribbon cables and a few heavy duty wires.

While all of the parts can be obtained from virtually any large electronics retailer, the 0.1Ω 5W shunt resistors can be replaced with less common 1% types (or better) for improved current measurement accuracy. Alternatively, use a millivoltmeter to test a number of 5% resistors for accuracy. We chose two at random for our first prototype and as luck would have it, they were within 1%.

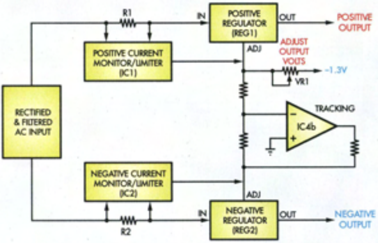


Fig.1: this block diagram shows the basic operation of the supply. Variable regulators REG1 & REG2 provide the positive and negative output rails, while IC4b ensures that REG2 tracks REG1. R1, R2, IC1 & IC2 monitor the rail currents and provide limiting as necessary.

Features

Because this is a tracking supply, under normal conditions, the absolute voltage at the negative output matches that of the positive output. In other words, if the positive output is adjusted to +9.3V, the negative output will be -9.3V. As a result, only one voltage adjustment knob is required. Many circuits, especially those with op amps, work best with balanced rails.

The 5.0V output is supplied by a 7805T regulator, which has its own current and thermal limiting. This rail also powers the panel meter and power LED, so if you manage to short the output, it will be obvious! It's best to avoid shorting it if possible but if the display goes blank, disconnect the 5.0V output (or clear the short) to restore it.

The main current limit is controlled via a second knob on the front panel. You can view the current limit setting on the display while setting it accurately – there is no need to connect a load to make the adjustment.

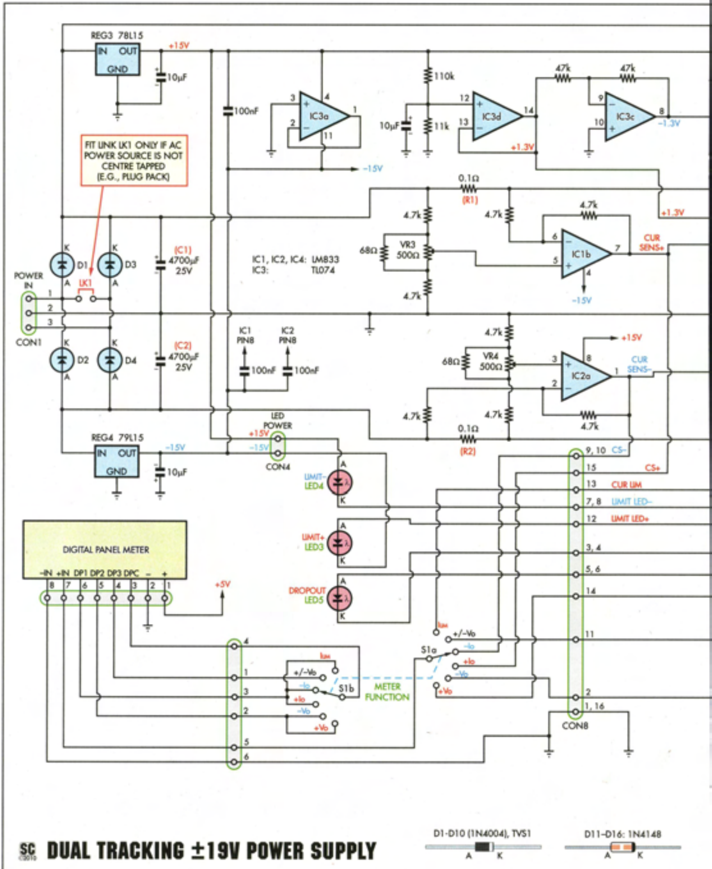
The current limit is applied for both primary outputs with a typical accuracy of ±3mA plus the measurement error. If the current from either primary output reaches the limit setting, that output voltage will drop as far as necessary to avoid exceeding the limit. This means you can also use the supply as a current source (from the positive rail) or sink (from the negative rail) by setting the voltage at maximum and the current limit as appropriate.

Our current limiting scheme is not a "foldback" design. With a foldback scheme, once the current limit is exceeded the output voltage drops virtually to zero until the overload is cleared. This provides better protection in the case of a dead short and limits power dissipation within the supply but foldback designs can not be used as a current source or sink and they can be unstable with reactive loads.

Because the two rails track, if the positive output is being current limited then the negative output voltage will also drop. However, the reverse is not true. If the negative output current limit is exceeded, the positive output voltage will not necessarily change. It has been designed this way to keep

Table 1: Specifications

	Internal Mains Transformer	External AC Plugpack
Output Voltage	±0-19V or +0-38V	
Output Current	Up to 1.6A (see Fig.5)	Up to 0.9A (see Fig.6)
Load Regulation	0.1% (0-1A)	0.1% (0-500mA)
Line Regulation (230V ±10%)	0.2%	0.2%
Noise (0-1A)	<525μV peak-to-peak (see Fig.7)	
Ripple (0-1A)	<1mV RMS, <1.7mV peak-to-peak (see Fig.7)	
Display	+ Voltage, - Voltage, + Current, - Current, Total Voltage, Current Limit	
Voltage Reading Accuracy	Typically <1%	Typically <1%
Current Reading Accuracy	Typically <2.5% ±10mA	Typically <2.5% ±10mA



SC ©2015 DUAL TRACKING ±19V POWER SUPPLY

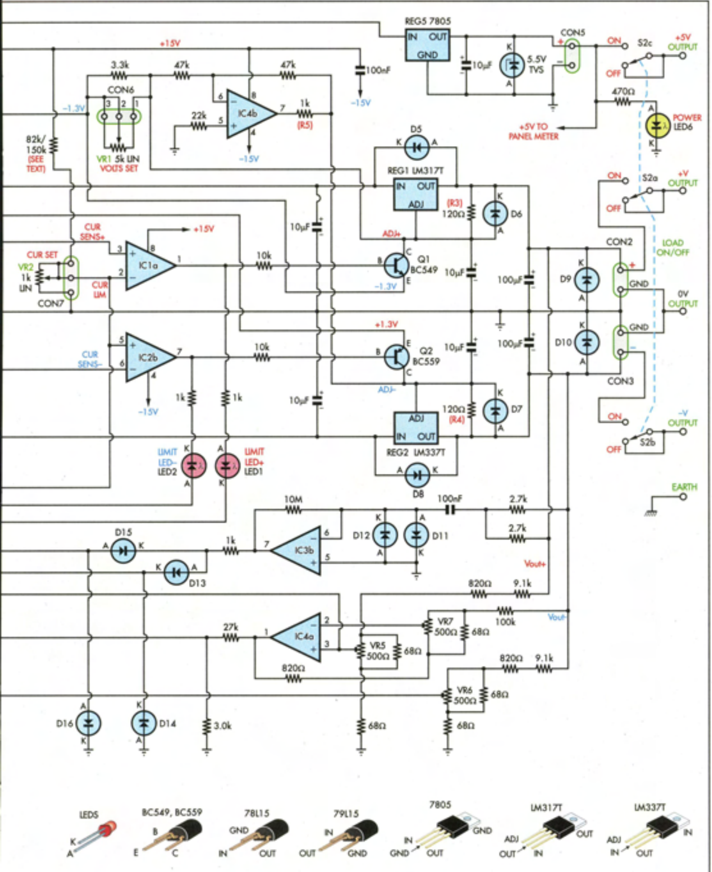


Fig.2: this diagram shows the complete circuit minus the mains transformer and the alternative plugpack supply. The parts shown with green labels mount on the front-panel PC board, while the remaining parts (except for the panel meter and power LED) are all mounted on the main board.

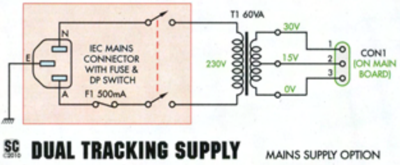


Fig.3: the mains-powered version uses an IEC connector with an integrated switch and fuse, plus a 60VA 30V centre-tapped mains transformer.

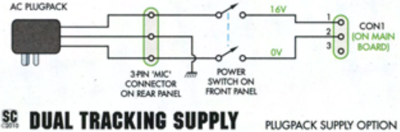


Fig.4: this supply option uses a 16V 1.38A AC plugpack which connects via a 3-pin microphone connector on the rear panel of the unit.

cost and complexity low.

You can also use the current limiting feature when "bridging" the outputs to get the higher voltage range.

Note that if you are close to drawing the maximum current available at a given voltage setting, the current limit may kick in early. This is indicated by the current limit and dropout LEDs lighting simultaneously and will be due to the large 100Hz ripple voltage on the filter capacitors in this condition. Generally, it's best to avoid using the supply right at its limit, in which case this condition is avoided.

Supply options

A mains transformer or AC plugpack can be used to run the supply. The only difference is the amount of current that can be drawn from the outputs at a given voltage setting. Note that slightly less current is available if you use the LED display instead of the LCD option, due to its own current consumption. This will be more noticeable with the plugpack version.

The specified mains transformer is a 30V 60VA type with a centre tap. It has twice the VA rating of our earlier design, so more current can be delivered at voltages above 10V. The transformer is connected via an IEC socket with integrated switch and fuse, to keep the wiring as simple as possible.

If you prefer to avoid mains wiring, you can use a 16VAC 22VA plugpack instead. Virtually all plugpacks have a single secondary winding so we can't use full-wave rectification. This means that the filter capacitors are charged at 50Hz instead of 100Hz, reducing the output current further.

The specified plugpack has an earth wire so the front earth terminal works with either supply option. We don't recommend that you use a plugpack with a higher voltage rating as it could overload the current sense amplifier inputs.

We assume that most constructors will opt for the 60VA power transformer. However, we are also presenting the AC plugpack version so that the project can easily be built by school students as part of the electronics syllabus.

LED or LCD panel

We have chosen a digital display (LED or LCD) because such displays are much more precise and are cheaper than analog meters.

The display options are the Jaycar QP-5580 3.5-digit high-brightness LED panel meter and the Altronics Q0571 3.5-digit LCD panel meter. Both are "common ground" types, ie, their power supply does not have to float relative to the voltage being sensed.

The QP-5580 LED meter is larger and slightly more expensive than the Q0571 LCD meter; the LED meter is also very bright and easier to wire up. Ultimately, both work well so the choice is yours to make.

There are six readings we want to show (see Table 1) so there is a 6-way rotary switch which selects the desired mode. One switch pole connects the selected voltage to the display's input and the other selects the appropriate decimal place location.

Heatsink

The aluminium rear panel of the case is used as a heatsink for the three main regulators. They must be electrically insulated from it but because they can dissipate up to 30W each, the insulation must have a low thermal resistance and therefore mica washers are specified, not silicone types.

If you want to make the supply run cooler or deliver more current at low voltages, a finned heatsink can be drilled and attached to the rear panel using the regulator mounting bolts. Either the Altronics H0550 or Jaycar HH-8555 is suitable since they have 10mm fin spacing and the regulator tabs are spaced just under 30mm apart but note that you will need M3 x 20mm mounting screws.

Circuit description

While the above account of the new power supply's features may imply a very complex circuit, the basic circuit is not much different from that our of original January 1988 design. This is depicted in the block diagram of Fig.1. It essentially consists of positive and negative regulators which are forced to track together by op amp IC4b.

IC4b is effectively a negative voltage follower. It works so that the voltage setting called for from the positive regulator REG1, by potentiometer VR1, is fed to its inverting input. IC4b then inverts the signal and feeds it to the ADJ terminal of the negative regulator, REG2.

There is a lot of ancillary circuitry which provides all the current limit and metering options but IC4b and the two adjustable 3-terminal regulators are the heart of the circuit.

Turning now to the main circuit of Fig.2, it is rather large but each section is quite simple in its operation. Despite the large number of op amps, there are in fact only four DIP IC packages on the board, plus five 3-terminal regulators (two in TO-92 packages) and two transistors. The remaining components are resistors, capacitors, diodes, LEDs and connectors.

Note that some of the components shown in Fig.2 are mounted on the front-panel PC board. These components are labelled with green text. The others are mounted on the main PC board. Several ribbon cables and heavy duty wires connect the two together, via connectors CON2-CON8.

The AC supply is shown separately in Figs.3 & 4 (depending on which version is being built). In either case, power from the mains transformer or AC plugpack is delivered to CON1, on the lefthand side of the circuit.

If a mains transformer is used, the AC waveform is full-wave rectified by diodes D1-D4. By contrast, for a plugpack, the secondary is connected between pins 1 & 2 and LK1 (on the main board) is installed. This connects the bridge diodes in parallel for half-wave rectification to give lower voltage losses.

The rectified voltage is filtered by capacitors C1 and C2, both 4700µF 25V (or higher), and the resulting DC rails are fed through shunts R1 and R2 to the main regulators REG1 and REG2 (over on the righthand side of the circuit). In addition, the 78L15/79L15 linear regulators REG3 and REG4 (left top and middle of the circuit) produce ±15V for the op amps.

The +15V rail is also used as a voltage reference for potentiometer VR2 and to generate the ±1.3V bias rails (more on these later).

Regulation

REG1 and REG2 are LM317T and LM337T adjustable regulators and are responsible for maintaining the correct output voltage and rejecting ripple from the AC supply. The 10µF capacitors across their inputs reduce the effect of the shunt resistance on the output voltage regulation.

The 10µF capacitors on the ADJ pins, in combination with the 100µF capacitors across the outputs, improve ripple rejection and reduce noise. Diodes D9 & D10 prevent voltages applied to the supply's outputs (eg, by an inductive load being switched off) from damaging any internal components.

REG1 and REG2 develop a nominal 1.25V between their OUT and ADJ terminals. With a 120Ω resistor (R3 & R4) connected between them, this means the quiescent current will be just over 10mA, which satisfies the minimum load requirement of the regulators.

REG1's output voltage is controlled by a potentiometer (VR1) connected between ADJ and -1.3V. This acts as a voltage divider in combination with R3.

If VR1 is set to, say, 1kΩ and the voltage across R3 is 1.25V then the voltage across VR1 will be 10.42V. In

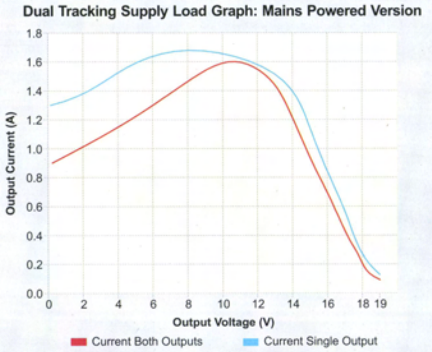


Fig.5: the load graph for the mains-powered version. It shows the maximum current available at any voltage setting before dropout for both dual outputs and a single output.

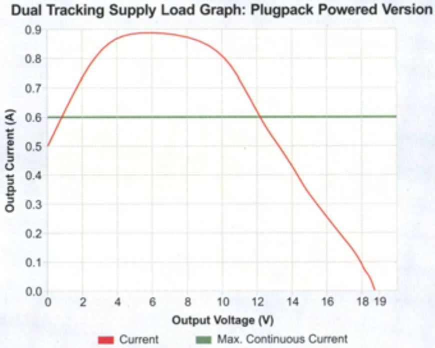


Fig.6: the load graph for the plugpack version. The curves are the same for both dual outputs and for a single output. Note that the total continuous current drawn from all outputs should not exceed 600mA.

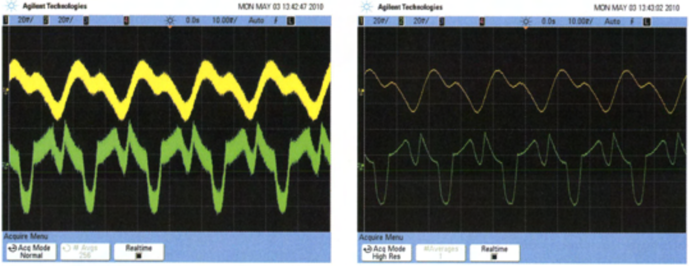


Fig.7: these scope grabs show the amplified noise and ripple at the outputs (yellow positive, green negative). The maximum ripple is 600µV RMS (1200µV p-p) at 1A for the positive rail and 940µV RMS (2200µV p-p) for the negative rail. The righthand scope grab shows the waveforms after averaging, which removes the noise component.

this case, the output voltage is 10.42V - 1.3V + 1.25V = 10.37V.

VR1 is mounted on the front-panel board and is connected to the main board via CON6. It has a 3.3kΩ resistor in parallel which sets the maximum output to 19.5V.

The -1.3V bias is important since it allows the output to be adjusted down to 0V. Without this, the ADJ pin could only go to 0V and so the output would not go below 1.25V. The -1.3V bias is slightly more than is necessary to account for regulator and resistor variations.

This -1.3V rail is generated by op amp IC3c, connected as an inverting amplifier. Its input is +1.3V which is generated by IC3d. IC3d is a voltage follower with its input tied to a voltage divider (110kΩ/11kΩ) between +15V and 0V.

Tracking

As noted earlier, op amp IC4b is responsible for the negative output voltage tracking the positive output (see the block diagram of Fig.1). Because we know the voltage across R3 and R4 is maintained at 1.25V, if the ADJ terminal voltages track, then so will the output voltages.

IC4b's output supplies current to REG2's ADJ terminal via 1kΩ resistor R5. Since there is 1.25V across R4, the current through R5 must be about 10mA. This means there is always 10V across R5.

Because IC4b's output can swing over a range of at least ±12V, REG2's ADJ pin can be controlled over a range of +2V to -22V, allowing tracking across the full range of output voltages.

Current sensing

The current flowing to the positive and negative outputs passes through resistors R1 and R2 (0.1Ω). The voltage drop across them is sensed by op amps IC1b and IC2a (each half an LM833).

IC1b and IC2a are configured as differential amplifiers with a gain of one. The output is ground-referenced and directly proportional to the drop across the sense resistor. For example, if there is a 50mV drop across R1, the output of IC1b will be close to 50mV and similarly for R2 and IC2a. IC2a's inputs are swapped relative to IC1b because current through R2 goes in the opposite direction.

Consider the voltage at pin 5 of op amp IC1b, the non-inverting input. Assuming precisely equal resistors and that VR3 is centred, it is exactly half the voltage across C1. If no current flows through R1 then pin 6 of IC1b, the inverting input, is at the same potential. Since the difference between the inputs of IC1b is 0V, its output should be at 0V.

As current begins to flow through R1, the voltage at pin 6 of IC1b decreases due to the voltage drop across R1. However, the voltage at pin 5 remains the same so the output of IC1b must rise to bring pin 6 up to the same voltage as pin 5. If the drop across R1 is 0.1V then IC1b's output must rise by 0.1V for the two inputs to remain at the same voltage.

Because a differential amplifier requires very accurately matched voltage dividers to operate correctly, we can't rely on the 1% tolerance resistors; they're not good enough. Trimpot VR3 allows the dividers at the inputs of IC1b to be adjusted so that their ratios match. VR4 does the same job for IC2a.

Ideally, we would use 50Ω or 100Ω trimpots (1-2% of 4.7kΩ). A higher value makes accurate adjustment too tricky. Since trimpots below 500Ω are hard to get, we have shunted 500Ω trimpots with 68Ω resistors. The resulting adjustment range is similar.

Because the inputs of the LM833s sit at half of the pre-regulated supply voltage and their guaranteed input voltage range is ±12V (typically ±14V), the maximum voltage across C1 and C2 should not exceed 24V. We have tested the mains-powered version and ensured that it does not exceed 24V with the maximum permissible supply voltage in Australia (230V+10% or 253V as per AS60038-2000).

For the plugpack version, if the mains voltage is well above 230V, the filtered voltage can be as high as 25.5V. In this case, the LM833's input voltage is still within typical specification. In the highly unlikely event that this affects the current limiting, that IC will need to be replaced with another sample.

Current sense errors

The combination of 0.1Ω shunt resistors and a differential gain of one means that the current sense outputs have a scale of 100mV/A. This is perfect since the panel meters we are using have a 200mV full scale. We can display currents up to 1.999A with 1mA resolution by enabling the decimal place after the first digit.

However, the reading precision is not as good as this resolution. While we have found that it is possible to trim the output to within 1mA of the correct value, there are four sources of error:

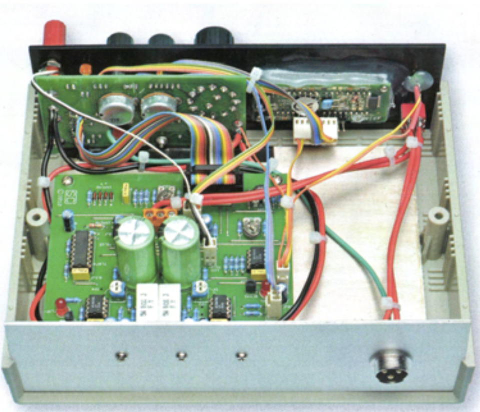
(1) The tolerance of R1 and R2. Common 0.1Ω resistors are only guaranteed to be within 5%. In practice, they are generally much closer than that but better results can be obtained with 1% resistors rated at 0.5W and above (eg, Farnell 1653230).

(2) The measurement includes about 10mA that is consumed by the regulator circuits. This is unavoidable since if we place the shunts after the regulators, we will seriously prejudice the load regulation of the supply. This error can be trimmed out with VR3 & VR4 but doing so inevitably degrades common mode rejection and possibly increases the scale error.

(3) IC1 and IC2 have an input offset voltage error, which results in a similar error at the output. We have chosen the LM833 for IC1, IC2 & IC4 because it is a common chip with a low input offset voltage, typically below 0.3mV. This represents an error of up to 3mA which can be trimmed out at the same time as the regulator current error.

(4) Due to the extreme resistor matching requirements, temperature drift is an issue. Since the divider resistors do not heat up and cool down at exactly the same rate, the divider ratio drifts. We have found that reducing the divider resistor values reduces temperature drift so have settled on 4.7kΩ.

Once the supply is trimmed and after it has warmed up, the error is typically no more than ±3mA plus 1% of the reading. The error when cold is more like 15mA, so for accurate readings, let the supply warm up first.



This internal view shows the completed plugpack-powered version of the supply. It can be built into a smaller case than the mains-powered version.

Current limiting

VR2, the 1kΩ current limit adjustment potentiometer, connects to the main board via CON7. It acts as a voltage divider with either an 82kΩ resistor (mains version) or 150kΩ resistor (plugpack version) to generate a voltage in the range of 0-170mV (or 0-100mV). This represents a current limit of 0-1.7A (or 0-900mA for the plugpack powered version).

This voltage, along with the current sense voltages, is fed to op amps IC1a & IC2b. Let us consider IC1a when the current sense voltage is below the preset limit. In this case, IC1a's pin 1 output will be low (about -13V), keeping NPN transistor Q1 and LED1 turned off.

If the current sense voltage exceeds the preset limit, IC1a's output swings positive, turning on Q1 and LED1 (along with the corresponding front-panel LED, LED3). Hence, Q1 pulls REG1's ADJ pin low, reducing REG1's output voltage. A steady state is reached in which the output current flow is just below the current limit and Q1 is held partially on.

Because the LED current partly depends on how much current is being sunk from the ADJ pin, the degree of overload is indicated by the brightness of the limit LEDs (LED3 & LED4).

If the load current is reduced, Q1 turns off and REG1's output voltage returns to normal. Q1's emitter is connected to -1.3V, for the same reasons as previously mentioned with respect to VR1. The output voltage needs to be brought down nearly to 0V in cases of severe overload (eg, short circuits).

While LED1 may be helpful during testing, its real purpose is to add an approximate 2V drop between the output of IC1a and LED3. This is necessary because LED3's cathode is connected to -15V but IC1a's output can only swing to -13V. Without this additional drop, LED3 would not turn off properly. A 1kΩ resistor provides current limiting for both.

Current limiting for the negative output operates identically but is controlled by IC2b which drives Q2. When Q2 is turned on, so are LED2 and LED4. Q2's polarity and voltages are reversed compared to Q1 and the LEDs are connected in the opposite manner.

With the plugpack-powered version, it is a good idea to keep the current limit setting below 500mA. Otherwise, if a dead short is placed across the outputs, the ±15V rails can drop and the output current will only be limited by REG1 & REG2's internal circuitry.

LED dropout indicator

If high currents are drawn from the regulated outputs, the ripple voltage across the main filter capacitors, C1 & C2, will increase to a high level and as result, the outputs may no longer be properly regulated and there will be hum superimposed on the DC voltage.

This is the completed mains-powered version with the Altronics 3.5-digit LCD readout. The Jaycar LED readout can also be used – details next month.

This is clearly undesirable, so a dropout LED is mounted on the front panel. It lights if there is any significant AC component on either output. Two 2.7kΩ resistors mix the output voltages and the DC component is removed by a series 100nF capacitor. This signal is clipped to a maximum of 0.7V peak-to-peak by D11 & D12 and is then amplified by IC3b.

The gain is around 575 (taking into account the impedance of the 100nF capacitor) and the resulting signal is then rectified by D13-D16 and applied to the dropout LED (LED5) on the front panel. This LED is a red, high-brightness type and lights dimly with just a few millivolts of ripple on either output, growing progressively brighter with increasing ripple. It is quite bright by the time the ripple waveform reaches 100mV peak-to-peak.

5V fixed output

REG5 provides a fixed 5V output at up to 1A to power the 3.5-digit LED or LCD panel meter. Since the panel meter doesn't need anywhere near 1A, it is also fed to a binding post on the front panel so it can be used as a low-current auxiliary output.

Transient voltage suppressor TVS1 protects the circuit in case the 5V output is shorted to either the main positive or negative outputs. If it is shorted to a positive voltage in excess of 5V, the 5V rail voltage will rise and TVS1 clamps the 5V rail to around 7-8V to protect the panel meter (Note: a 6.8V 5W zener diode can be used instead of TVS1 – see next month).

If the positive rail current limit is set at its maximum, TVS1 could be conducting around 1.5A and dissipating 10W or more. TVS1 is only rated to dissipate that much power for about two seconds and if the short is maintained, TVS1 will ultimately fail.

This means that if such a short occurs, then the load or power should be switched off immediately.

By contrast, if the 5V output is shorted to the negative output, TVS1 is forward-biased and prevents the 5V rail from dropping below about -1V. Dissipation in this case is far less but it's still a good idea to disconnect the outputs as soon as possible.

The only remaining circuitry on the main board consists of the three voltage divider networks for driving the display. Since the panel meter is 200mV full-scale (ie, 199.9mV is displayed as 1999), we must divide the output voltages down by a factor of 100. A voltage of, say, 10V becomes 100mV which is displayed as "10.00".

The upper portion of these voltage dividers consists of 9.1kΩ and 820Ω resistors in series, for a total resistance of 9920Ω. The lower portion consists of two 68Ω resistors, one of which is in parallel with a 500Ω trimpot (VR5). By adjusting the trimpot, we can get very close to having an exact 100:1 ratio.

Resistor temperature drift is the most significant issue for making accurate readings and keeping the total resistance to 10kΩ or below helps significantly.

The third reading to be generated is the voltage across both rails, which is monitored by IC4a, another differential amplifier. The positive rail 100:1 divider for the panel meter is re-used, but the negative divider is not since it needs separate trimming. Once again, we are using a 500Ω trimpot (VR7) in parallel with a 68Ω resistor to compensate for any errors.

Because this reading can go above 20V, it must be further divided by 10 to stay within the 200mV range of the panel meter. A 10:1 divider on the output of IC4a (27kΩ and 3kΩ) gives the correct voltage level.

Front panel board

To simplify construction, the following components are mounted on the secondary PC board: the 6-way meter function switch S1, voltage and current adjustment potentiometers VR1 & VR2, LEDs3, 4 & 5, load switch S2 and the five binding posts – positive output, 0V, negative output, 5V output and earth.

As can be seen from the circuit of Fig.2, the load switch can disconnect all three outputs from the regulators.

The six readout signals are delivered to the front panel from the main PC board via a 16-way ribbon cable. Switch S1a connects the selected signal to the panel meter. At the same time, the other half of switch S1 (S1b) selects the appropriate decimal place for that reading.

A 6-pin connector joins the front panel to the panel meter. It carries the voltage reading to be displayed and its ground reference, plus the wires to select each decimal place. At any one time, one of the three decimal place wires is connected to the common wire and the other two are disconnected. The 5V power for the panel meter comes directly from the main board.

The two primary regulated outputs

Parts List

1 PC board, code 04206101, 113 x 105mm (main board)
1 PC board, code 04206102, 98 x 58mm (front panel board)
1 PC board, code 04206103, 63 x 28mm – required only if LCD panel meter used
2 2-way small screw terminal blocks (5.08mm pitch)
1 3-way small screw terminal block (5.08mm pitch)
1 8-way polarised header connector (2.54mm pitch)
2 3-way polarised headers (2.54mm pitch)
2 3-way polarised header connectors (2.54mm pitch)
2 2-way polarised headers (2.54mm pitch)
2 2-way polarised header connectors (2.54mm pitch)
1 16-way IDC vertical connector (2.54mm pitch)
1 16-way IDC line socket
3 TO-220 mica insulating pads with bushes
4 9mm tapped Nylon spacers
3 M3 x 10mm pan head machine screws
8 M3 x 6mm pan head machine screws
3 M3 nuts
1 3PDT miniature toggle switch
1 6-way 2-pole rotary switch
2 black push-on knobs to suit pots
1 black 24mm knob to suit
5 binding posts (red, black, white, green, yellow)
1 1m-length 0.71mm tinned copper wire
1 500mm length 16-wire rainbow ribbon cable
Heavy duty hookup wire (1m red, 500mm green/yellow, 500mm black)
1 50mm length heatshrink tubing (3mm diameter)
1 3.5-digit LED panel meter (common ground) (Jaycar QP-5580) *or* 3.5-digit LCD panel meter (common ground) (Altronics Q0571)
15 small cable ties
1 small quantity of thermal grease
1 8-way 90° polarised header (2.54mm pitch) – required only if LCD panel meter used
1 5kΩ 16mm linear potentiometer (code 502) (VR1)
1 1kΩ 16mm linear potentiometer (code 102) (VR2)
5 500Ω horizontal trimpots (code 501) (VR3-VR7)

Plugpack version only
1 plastic instrument case, 200 x 158 x 64mm (Jaycar HB-5912, Altronics H0480F)
1 16VAC 1.38A AC plugpack with earth lead (Altronics M9332A)
1 DPDT miniature toggle switch
1 3-pin male chassis mount microphone socket (Altronics P0954)
1 3-pin female line microphone connector (Altronics P0949)
1 aluminium sheet, 190 x 60mm, or Altronics H0486 for rear panel
1 aluminium sheet, 170 x 127mm
1 5.3mm eyelet crimp lug
1 M4 x 15mm pan head machine screw
1 M4 star washer
1 M4 nut
4 No.4 x 6mm self-tapping screws

Mains powered version only
1 plastic instrument case, 260 x 190 x 80mm (Jaycar HB-5910, Altronics H0482)
1 60VA 30V centre-tapped mains transformer (Jaycar MM2005, Altronics M6674L)
1 chassis-mount IEC socket with fuse and power switch (Jaycar PP4003, Altronics P8341)
2 500mA M205 fast-blow fuses (1 spare)
1 aluminium sheet, 248 x 76mm for rear panel
1 aluminium sheet, 224 x 155mm
7 4.8mm insulated spade crimp lugs
7 5.3mm eyelet crimp lugs
7 M4 x 15mm pan head machine screws
4 M4 spring washers
6 M4 star washers
10 M4 nuts
6 No.4 x 6mm self-tapping screws
1 200m length 5mm diameter heatshrink tubing

Semiconductors
3 LM833 dual op amps (IC1, IC2, IC4)
1 TL074 quad op amp (IC3)
1 LM317T adjustable regulator (REG1)
1 LM337T adjustable regulator (REG2)
1 78L15 linear regulator (REG3)
1 79L15 linear regulator (REG4)
1 7805 linear regulator (REG5)
1 BC549 small signal transistor (Q1)
1 BC559 small signal transistor (Q2)
10 1N4004 diodes (D1-D10)
6 1N4148 diodes (D11-D16)
1 P4KE6.8 5.5V transient voltage suppressor (TVS1) or 6.8V 5W zener diode
2 5mm red LEDs (LED1, LED2)
2 5mm amber or orange LEDs (LED3, LED5)
1 5mm high-brightness red LED (LED4)
1 5mm green LED (LED6)

Capacitors
2 4700μF 25V or 35V electrolytic
2 100μF 25V electrolytic
8 10μF 25V electrolytic
5 100nF MKT polyester

Resistors

1 10MΩ	8 4.7kΩ
1 110kΩ	1 3.3kΩ
1 100kΩ	1 3kΩ
4 47kΩ	2 2.7kΩ
1 27kΩ	4 1kΩ
1 22kΩ	3 820Ω
1 11kΩ	1 470Ω
2 10kΩ	2 120Ω
2 9.1kΩ	7 68Ω

2 0.1Ω 5W 5% or 0.1Ω 1W 1% (Farnell 1653230)
1 150kΩ (mains version) or 82kΩ (plugpack version)

and their ground returns, as well as earth, are connected to the front panel via heavy duty wire. Because the front panel carries the load switch and output terminals, no extra wiring is necessary. However, the main power switch, power LED and panel meter are mounted separately.

That's it for this month. Next month we will describe how to build the PC boards, install them in the case and wire it all up. **SC**