one for PCB mounting. It may be possible to bend these eyelets slightly outwards to give more space for the resistors

If a digital meter module is used, do not forget to wire switch section S_{1c}, which controls the decimal points

In spite of there being six preset potentiometers, the calibration of the instrument is fairly straightforward. Start with setting all the presets to the centre of their travel

If a moving coil meter is used, connect a voltmeter between D and earth. With the instrument switched off, zero the moving-coil meter manually. When a digital meter is fitted, an external voltmeter is not required

Set S_2 to position C(apacitor) and leave the input terminals open. Adjust P_4 till the voltmeter (or internal digital meter) reads 0. This arranges the offset compensation

Connect two 100 nF in parallel to the input terminals and set the range switch to 200 nF. The value of these capacitors need not be accurate, since this test only serves to set the gain of IC_{2c}. This is done by adjusting P_3 until the voltage at D is 2 V. Because of R_{27} and C_7(τ = 1 s), this voltage rises only slowly; P_3 should, therefore, be adjusted slowly also. When P_3 has been adjusted as required,connect a resistor of 10 kΩ in parallel with the 100 nF capacitors. Then adjust P_1 to return the voltage at D to 2 V. This arranges the phase difference between sinusoidal and square-wave signals at 90°

Next, remove the 10 kΩ resistor, but not the capacitors, from the input terminals. Ideally, P_2 should be set with its wiper at the output of IC_{2b}. This would, however, create a positive feedback loop with a gain of ×1: not exactly conditions for oscillation, but very nearly so. It is, therefore, necessary to connect an oscilloscope to the output of IC_{2b} and adjust P_2 so that oscillation just does not set in. If an oscilloscope is not available, set P_2 to about ¾ of its travel, that is, 750 Ω between wiper and earth

If, apart from an oscilloscope, a function generator that provides a triangular output is available, P_2 can be adjusted even more accurately. To that end, R_{13} must be unsoldered from IC_{1c} and a 3-V, 1 kHz triangular signal applied across it. An oscilloscope connected to the output of IC_{2b} will then show a square wave-form (because of the integrating action of the capacitors at the input). Adjust P_2 so that this wave-form is 'clean', that is, shows no overshoot

Connect two 100 nF, 1%, capacitors (if a moving coil meter is used) or an 180 nF, 1%, capacitor (if a digital display is used) to the input terminals and adjust P_6 (moving-coil meter) or P_3 (digital display) until the correct value is read ■

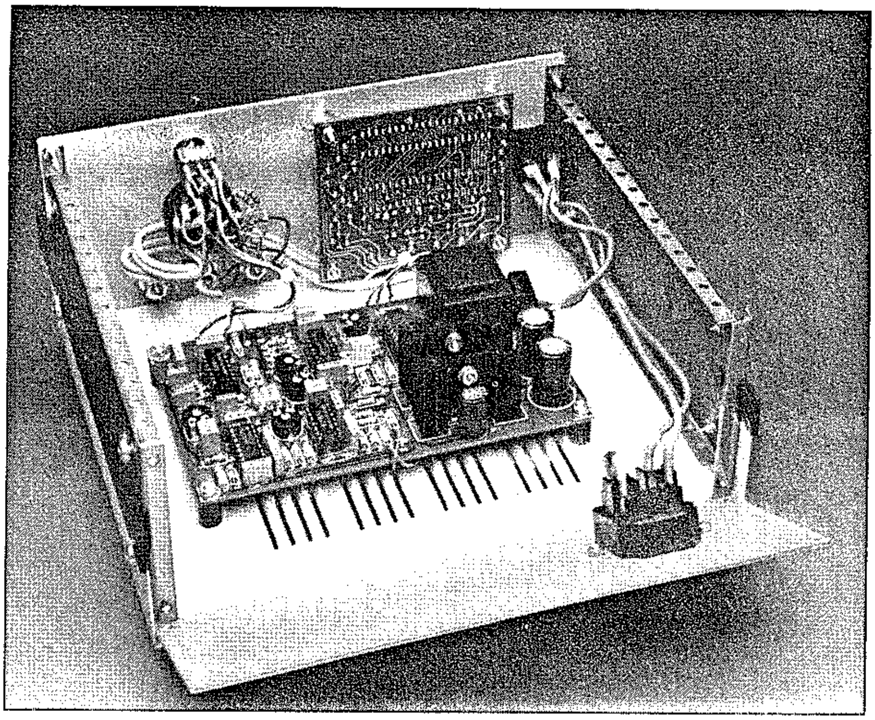

Fig. 8. Inside view of meter with top panel removed and rear panel hinged down.

MEASUREMENTS ON POWER SUPPLIES

by our technical staff

How do you know whether your precious laboratory/workshop power supply unit is still working to specification? How do you measure the parameters of the PSU you have just built or purchased for fitting into an electronic apparatus and what do you specifically have to look out for? The answers to these and many other questions connected with the testing of power supplies are given in this practice-based article.

THE requirements of a laboratory/workshop power supply unit are exacting. Not only the output voltage and current, but also the dynamic and static internal resistance noise, overshoot and thermal stability to name but a few are important. *Any electronic apparatus is only as good as its power supply* is an adage that remains true.

The extent to which a power supply can be tested depends primarily on the available test equipment. Normally, the output voltage can be measured with a simple multimeter

But even this measurement may be more complicated than appears at first sight. Imagine, for instance, that you have obtained a 6 V mains adapter to replace the batteries in a normally battery-operated apparatus, which is not only less expensive in the long run, but also more sensible from an ecological viewpoint. To your surprise, when you measure the output voltage, it is 9–11 V. The first question that pops into your mind is: 'Is it safe to connect to the equipment?' Practical considerations show that there is no harm in that whatsoever. The explanation for this statement is that such a simple mains adapter usually consists of a small transformer, rectifier and reservoir capacitor, nothing more. For all sorts of reason, small transformers generally have a fairly high internal resistance —

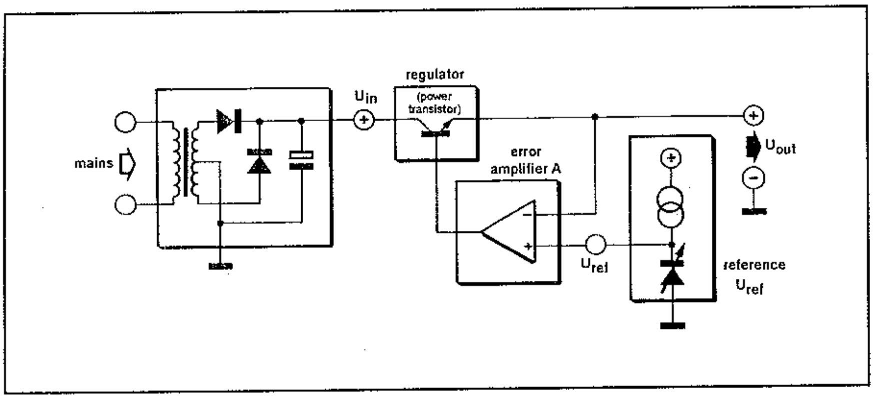

Fig. 1. Basic circuit of a regulated power supply. The quality of the supply is determined primarily by the regulator section.

of the order of a few ohms—and this makes the output voltage highly dependent on the output current. In other words, the e.m.f. is appreciably higher than the nominal (on-load) output voltage: if the load is small, the output voltage is high. That is why the load voltage is normally specified at a certain output current.

It is, therefore, essential to know how a parameter, even one as simple as the output voltage, is measured.

Parameters

In contrast to a simple mains adapter, a regulated power supply is designed to nullify the effect of different loads on the output voltage. In general, the more complex the design, the more the supply will approach the ideal. A perfect power supply has, irrespective of its application, some basic properties: it shall in all circumstances provide a constant output voltage, on which there is no ripple, noise or other spurious signals.

The following list shows which properties determine the quality of the supply.

Load voltage: the voltage that the supply will provide to a load over the nominal range of output currents.

Electro-motive force: the output voltage under no-load conditions; ideally, the e.m.f. and the load voltage should be identical.

Nominal output current: the current that the supply can deliver to the load without becoming overloaded.

Internal resistance: ideally, this should be 0 Ω, but all values in mΩ are good. It is sub-divided into:

Static internal resistance: this is discernible when the input voltage and the load remain constant with time.

Dynamic internal resistance: this is discernible only when the load changes with time.

Load regulation: this gives a measure of the fluctuations in the load voltage as the load current changes; it should ideally be infinitely large. The smaller the internal resistance, the better the load regulation.

Line regulation: this should ideally be infinitely large. It is a measure of the effect changes in the input voltage have on the nominal output voltage.

Ripple: this should ideally be fully suppressed. When rectification is full-wave its frequency is twice the mains frequency. The larger the regulating factor, the smaller the ripple at the output.

Noise: ideally, there should not be any. It originates primarily in the reference voltage source and in components in the regulator section.

Overshoot and undershoot: the regulating process causes small (mV range), short-duration deviations from the load voltage. Ideally, these should not occur.

Long-term stability: affected primarily by ageing processes in the reference voltage source; ideally, the load voltage should not change with time.

Thermal stability: dependent mainly on the quality of the voltage reference source; the load voltage should ideally not vary with changes in ambient temperature.

Power dissipation: this should ideally be small; it is the product of the voltage drop across the regulator and the load current plus losses in the transformer and rectifier.

Overcurrent protection: this becomes active when the load current starts to exceed its nominal value. It is required not only to guard the load from excessive currents under fault conditions, but also to protect the power supply from damage.

Short-circuit protection: ideally, the supply should be able to withstand a short-circuit indefinitely; the protection is often combined with overcurrent protection.

Power supply operation

The basic circuit diagram of a regulated power supply is shown in Fig. 1. The input section consists of the mains transformer, rectifier and filter capacitor. The remainder, regulator, error amplifier and reference voltage source, is required for regulating the load voltage. The entire regulating circuit can be housed on an integrated chip, such as those in the 78xx series.

The quality of the power supply depends primarily on the excellence of the regulating section. Nevertheless, although the internal resistance of the supply, and thus its load regulation, is highly dependent on the gain of the error amplifier, the internal resistance of the transformer, rectifier and reservoir capacitor also play a role.

If the total (static) internal resistance of the input section is, say, 2 Ω, and the amplification of the error amplifier is $\alpha = 1000$, the total (static) internal resistance of the supply is 2 mΩ. This ignores, of course, the resistance of the wiring, the PCB tracks, and so on. The amplification available for regulation consists of the open-loop gain and the closed-loop gain. The latter corresponds to the line regulation (≈ change in input voltage/resulting variation in output voltage).

Setting the amplification very high to reduce the internal resistance to an absolute minimum is not a practical proposition, because, since the error amplifier and power transistor require a finite time to react to changes, the build-up or decay transients increase in proportion to the amplification.

When top quality is required, close attention should be paid to the design of the mains transformer, particularly its (static) internal resistance. Above all, it should be designed so as to meet its requirements handsomely. C-type and toroidal cores, because of smaller stray losses, generally result in smaller internal resistances than the conventional laminated cores.

The capacitance of the reservoir capaci-

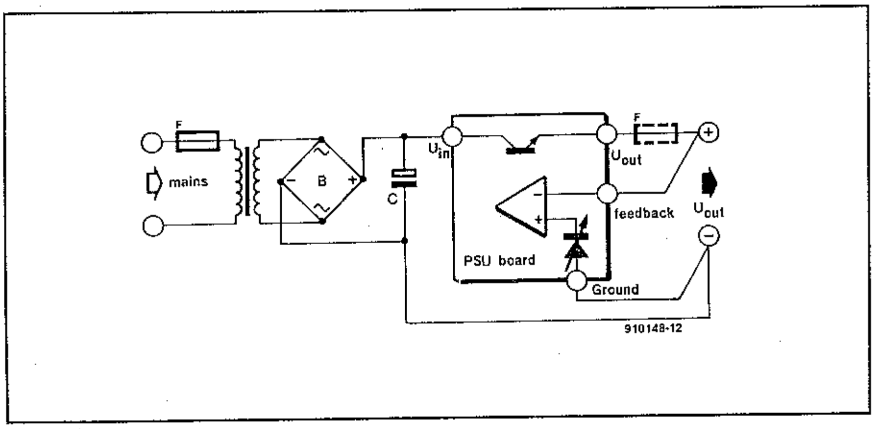

Fig. 2. Wiring diagram of a regulated power supply showing how the unit should be wired up. Note the location of the fuse(s).

tor affects not only the dynamic internal resistance, but also the ripple on the load voltage.

The thermal stability and noise are determined primarily by the reference voltage source Three-terminal voltage regulators normally have this source on board which therefore gets as hot as the power transistor—not an ideal situation

Noise and other spurious signals can normally be reduced appreciably by shunting the voltage source with a small foil-type decoupling capacitor

Apart from the quality of the reference source itself, the power supplied to it is also important and should, therefore, be regulated

It is, of course essential that a power supply is wired correctly If the general diagram in Fig 2 is followed, and heavy-duty wire is used the internal resistance and ripple will be a minimum

Fuses should, in general, be located in the +ve input (UK: 'live') line to the mains transformer Added security is obtained by a fuse between the power transistor and the feedback take-off for the error amplifier (as shown in dashed lines in Fig 2). The voltage drop across the fuse is compensated by the regulating process. The fuse must be located on the PCB

Measurement methods

The most important parameter of a power supply is its static internal resistance Fortunately. this can be measured fairly easily with a multimeter and a suitable load

Because of the greater accuracy of its read-out a digital multimeter is preferred. Moreover. the measurement accuracy of a digital multimeter, even of economy types, is generally better (error <1% on d c. ranges) than that of an analogue meter in the same price range.

During current measurements. the voltage drop across the meter is important: it should be small and even with large output currents not exceed 200 mV Note that many 3 ½ digit multimeters have no 200 mV range.

For a 12 V, 2 A power supply a 6 Ω, 24 W load is needed. This can, for instance, be made from five 33 Ω, 5 W resistors in parallel. The total resistance is then 6 6 Ω, but that is more an advantage than disadvantage. because the load current will then be 1.8 A, a value that can be read very accurately on most digital multimeters Note that the dissipated heat can easily burn the surface of a table or your fingers.

A better load is provided by a so-called resistor box containing for instance 20 or more 0 47 Ω, 5 W resistors that can be interconnected in various ways. Such a box (there are several varieties) can provide a variable load of 0 47–10 Ω rated at 3 A It is invaluable if a number of power supplies are to be tested.

First, measure the open-circuit output (electro-motive force—e m f), which is, say, 12 08 V Next. connect the 6 Ω load and measure the current through it, which is say, 1.836 A Then measure the voltage across the load. which is, say 11 98 V The difference between the e.m.f and the load voltage is thus 10 mV Since the load current is 1.836 A the internal resistance is $10\times10^{-3}/1.836 \approx 5.5$ mΩ a reasonably good value

If the internal resistance of the multimeter is not taken into account during the current measurement (when the meter is in series with the load) a small error results. If in the example discussed, the voltage drop across the meter was 186 mV (R_i = 100 mΩ) the calculated value of the internal resistance was 1.5% too large This error can be ignored. because the tolerance of the load causes a larger error (do not forget the increase in resistance caused by heating)

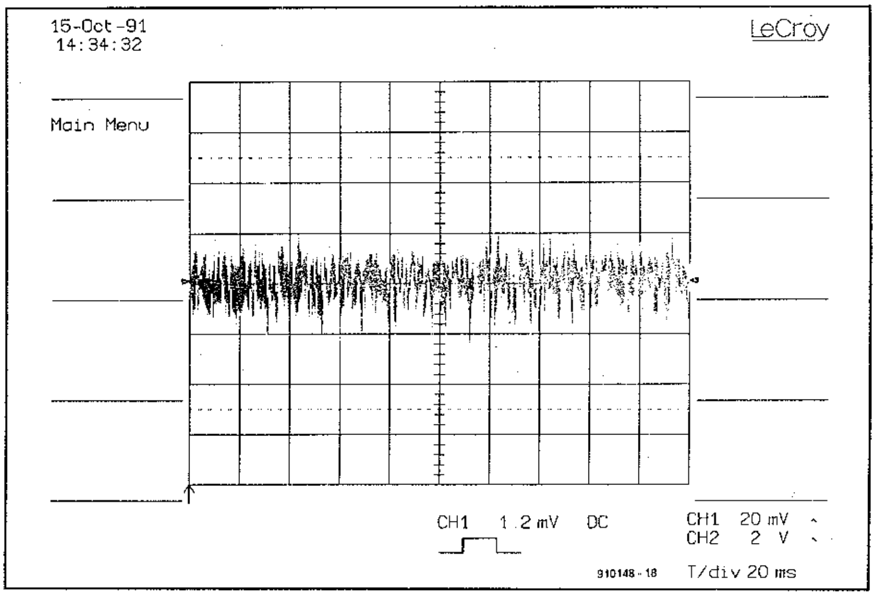

Fig. 3. Representation of noise output of a power supply as seen on an oscilloscope. Noise can be defined as random-frequency signals that extend over a considerable frequency spectrum.

To measure the dynamic internal resistance. and determine noise and ripple an oscilloscope is indispensable The scope connected across the output terminals. is set to its lowest a c range, normally 5 mV per screen division. and the time base to 10 ms per division Both noise. that is. random-frequency signals extending over a considerable frequency spectrum. and ripple. the unavoidable by-product of rectification here with a period of 10 ms are displayed—see Fig 3 and Fig 4 respectively The ripple will increase slightly when a load is connected to the supply As long as the peak-to-peak amplitudes do not exceed a few mV. all is well. If, however, on load, the ripple has a period of 10 ms and a peak-to-peak amplitude of sev-

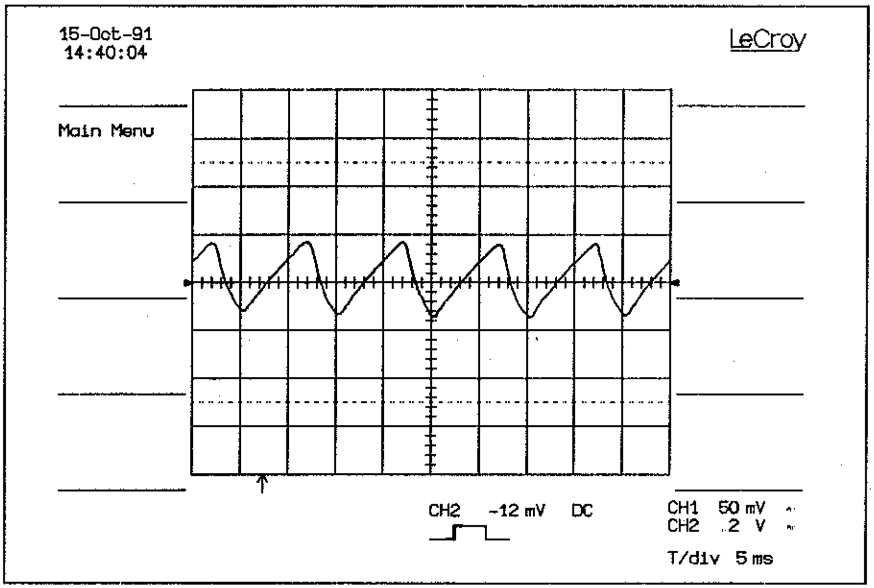

Fig. 4. Representation of a typical 100 mV ripple on the output of a power supply as seen on an oscilloscope.

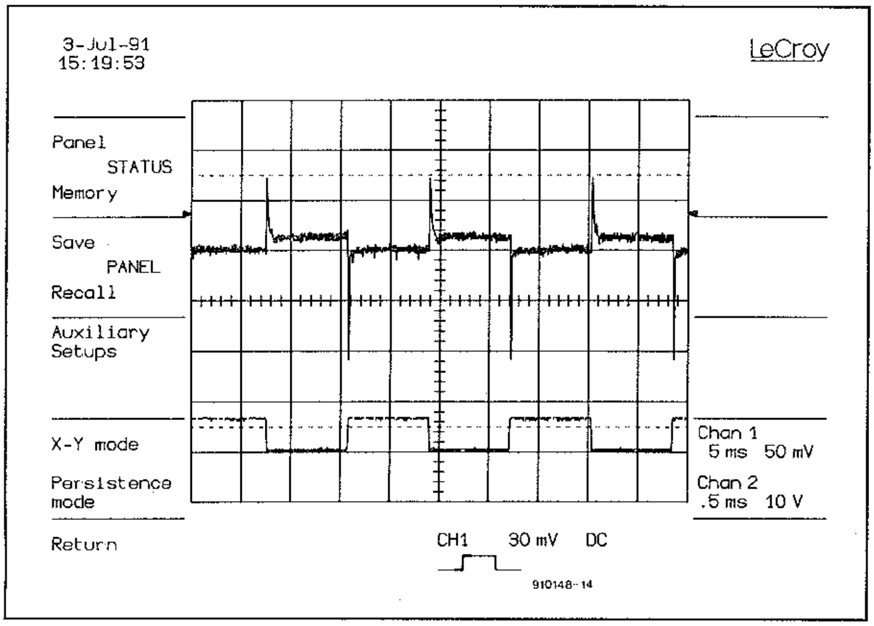

Fig. 5. Representation of the dynamic behaviour of the output voltage of a power supply (upper trace) loaded with the set-up of Fig. 6. The lower trace shows the drive (base signal) to T_1.

eral hundred mV the input voltage to the regulating section is too small. That means that either the current rating or the secondary voltage rating of the mains transformer is too low. The current rating should be some 1.5× the peak d.c. output current of the supply. The secondary voltage depends to some extent on the design of the regulator and on the capacitance of the reservoir capacitor. For instance, a rating of 12 V ~ for a 12 V power supply is clearly too low and should have been 15 V. It is, however, also possible, provided the ripple on load is small, to increase the value of the reservoir capacitor from, say 4700 µF to 10000 µF.

To ascertain the behaviour of the power supply with rapidly changing load values, its dynamic internal resistance must be determined and the load voltage observed on an oscilloscope. For this purpose, the rapidly changing load can be simulated by the set-up shown in Fig. 6. The function generator should be able to provide rectangular signals from a low-impedance (<50 Ω) output at a level of not less than 5 V p-p. This ensures full drive for T_1 which then draws a current of about 2 A. If a larger current is required, T_1 must be replaced by an appropriate darlington power transistor.

If a function generator is not available, a rectangular-signal generator can be built with the aid of the well-known Type 555 which is ideal for this purpose.

The transistor should be fitted on a small heat sink, since, in spite of the switching operation, it dissipates 2–4 W when the current is 2 A. If the power supply is rated above 45 V, it is advisable to use a sturdier type of transistor, for instance, the Type 2N3055.

The circuit in Fig. 6 is especially suitable for drive frequencies of up to about 2 kHz; note that 1 kHz is the typical frequency at which the dynamic behaviour of a power supply is usually determined.

With the function generator, set to 1 kHz, connected to the power supply via the circuit in Fig. 6 and an oscilloscope (time base set to 0.5 ms per division; amplification set to 10 mV per division) connected across the load, the screen display should be roughly as shown in Fig. 5. The upper trace shows that the regulator cannot follow the rapid changes. When the load is switched on, the load voltage initially drops sharply; only when the power transistor has resumed full drive does the load voltage return to its nominal value. The process on switch-off is similar: the regulator allows the power transistor to remain on for just a little too long. The duration of the voltage peaks in the upper trace gives an idea of how fast the regulator works.

The amplitude of the spikes can be reduced to some extent by a 100 nF capacitor across the output terminals or, preferably, directly across the load.

Apart from the overshoot and undershoot in Fig. 6 the trace also shows another, much smaller, variation with time when the load is constant. That tiny rectangular signal, superimposed on the load voltage, is caused by the dynamic internal resistance of the current source. Its magnitude is determined by reading the value of the rectangular signal on the oscilloscope screen (this is, say, 15 mV p-p) and divide this by the current through the load (measured with the multimeter in series with the load). To ensure that the current flows uninterruptedly during the measurement, the input of the circuit in Fig. 6 (R_I) is connected to, say, 5 V d.c. If the load current is, say, 1.77 A, the dynamic internal resistance is $15\times10^{-3}/1.77 = 8.5$ mΩ.

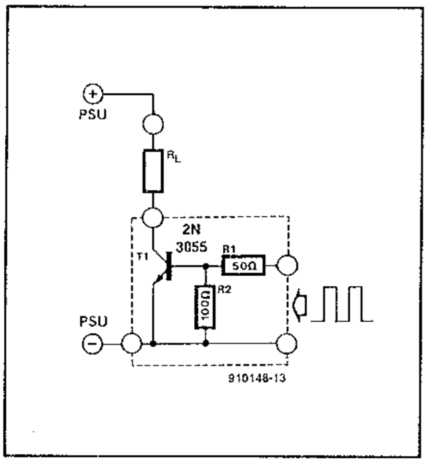

Fig. 6. Rapidly changing loads may be simulated by a power transistor and a rectangular-wave generator. Such a load enables the dynamic behaviour of a power supply to be determined.

What quality is required?

Now it has been shown what parameters of a power supply can be measured, and how, the question remains "what quality should a power supply have for a given application?"

For a.f. output amplifiers, a regulated power is normally not needed, but in the a.f. pre-amplifier(s) the suppression of noise and ripple are of paramount importance.

For small digital circuits, the quality provided by a three-wire regulator is normally more than adequate. Care should be taken with 5 V power supplies for complex digital circuits that contain TTL ICs (computers, for instance). Here, the 5 V load voltage should be set accurately to 5.15 V, since at lower values, because of the potential drop across the PCB tracks, the supply to some TTL ICs may become too low for reliable operation.

Power supplies for use in a laboratory or workshop are, as might be expected, the most demanding as regards noise, ripple, static/dynamic internal resistance and dynamic behaviour. Moreover, they should have a variable voltage/current output. All these facilities cost money, of course, and this cost should be considered in relation to the applications for which the supply is, or may be, needed. ■

***Useful literature*:**

Power Electronics Handbook by F.F. Mazda, Butterworths (1990), ISBN 0 408 03004 6

Electronic Instruments and Measurement Techniques, by F.F. Mazda, Cambridge University Press (1987), ISBN 0 521 26873 7

Design & Build Electronic Power Supplies by Irving M. Gottlieb, Tab Books (McGraw-Hill) (1991), ISBN 0 8306 6540 4.

High-frequency Switching Power Supplies, by George C. Chryssis, McGraw-Hill (1989) ISBN 0 07 010951 6