



Solid State

By Lou Garner

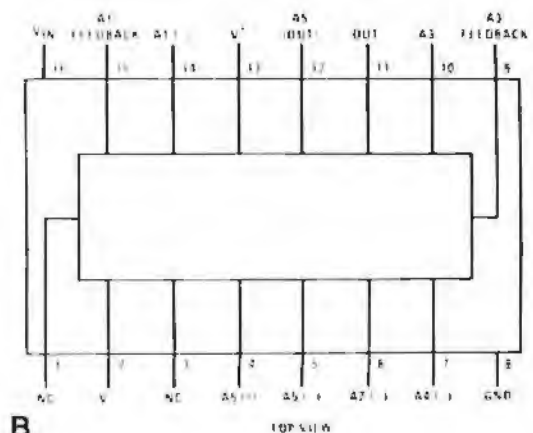
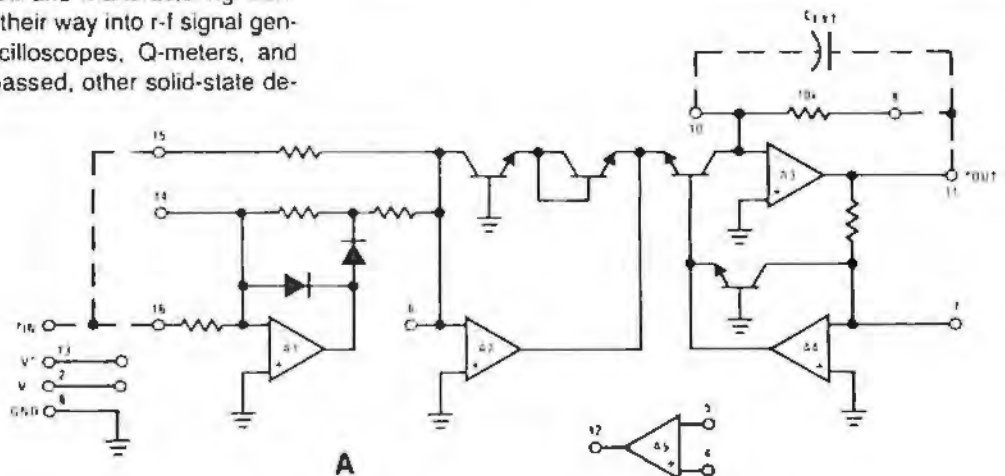
IC's FOR TEST INSTRUMENTS

SURPRISING as it may seem, solid-state test instruments were manufactured and used long before the transistor itself was invented. Featuring crystal diode circuitry, the early units were relatively simple instruments—r-f test probes, square-wave clippers, oscilloscope calibrators, dc reference voltage sources, outboard signal generator modulators, etc. Historically, the transistor's first significant commercial use was in hearing aids. Shortly thereafter, however, the recently invented device found its way into pocket AM radio receivers and, almost simultaneously, into portable test instruments. With its small size and low voltage and current requirements, compared to the then standard vacuum tube, the new device was certainly ideal for such applications. Initially, its use was limited to such products as signal tracers, simple meter amplifiers, and limited-range signal generators. Later, as better transistor designs were developed and manufacturing techniques refined, transistors found their way into r-f signal generators, function generators, oscilloscopes, Q-meters, and even microwave gear. As time passed, other solid-state de-

automatic ranging, frequency synthesis, automatic unit conversion, and digital counting and display.

Introduced recently by the National Semiconductor Corporation (2900 Semiconductor Drive, Santa Clara, CA 95051), the LH0091 is one of the latest IC's developed primarily for test instrument applications. Suitable for use in digital voltmeters (DVM's) and digital multimeters (DMM's) as well as in noise, vibration, audio and power meters, the new device is designed to generate a dc output equal to the *true rms value* of any ac or composite ac/dc input signal from 0 Hz (dc) to 2 MHz. With an inherent accuracy of 0.5% of reading, the device can be adjusted using external trimming for accuracies down to 0.5%. In typical applications, it has an input impedance of 5000 ohms and an output impedance of 1 ohm. When operated with a dual ± 15 -volt dc power source, the LH0091

Fig. 1. Simplified schematic (A) and lead connections (B) for LH0091 rms converter IC.



vices were added to test instrument complements, including FET's, SCR's, triacs, diacs, and LED's, culminating in the use of integrated circuits. Today, almost all solid-state test instruments use at least one IC and many a dozen or more. There are, in fact, a number of special-purpose IC's designed specifically for test instrument applications.

For the experimenter and hobbyist, the evolution of integrated circuits and the ready availability of special purpose IC's has made possible the home assembly of inexpensive but sophisticated test instruments which would be both costly and prohibitively large if based on the use of either vacuum tube technology or discrete semiconductor devices. In addition, the development of complex IC's has permitted the efficient use of advanced design concepts and techniques in test equipment design, including phase-locked loops, gyrators,

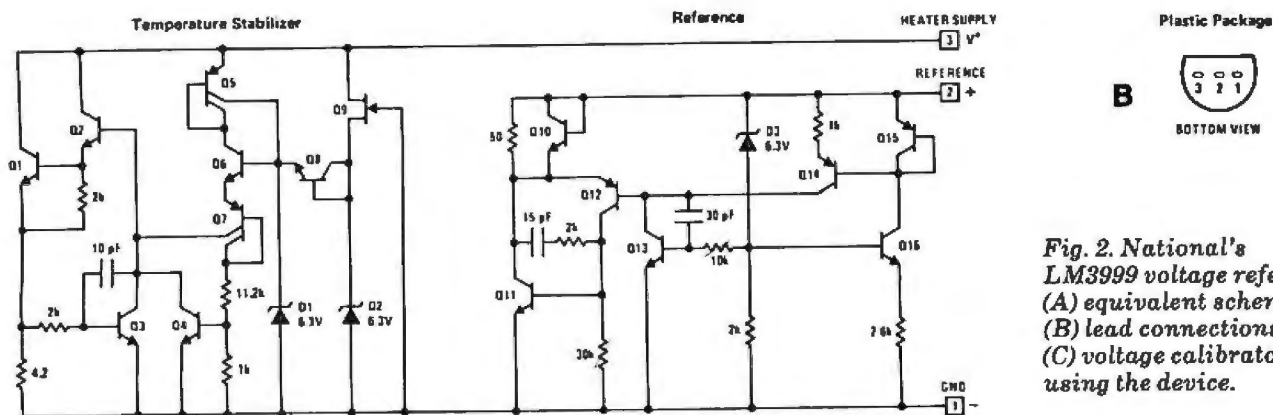


Fig. 2. National's LM3999 voltage reference: (A) equivalent schematic; (B) lead connections; (C) voltage calibrator using the device.

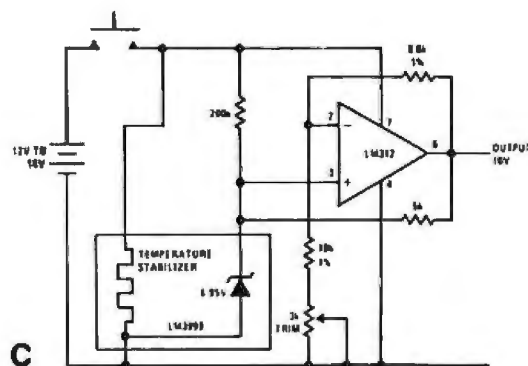
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will accept input signals of up to ± 15 volts peak. As shown in the unit's simplified schematic diagram, Fig. 1A, the IC includes an uncommitted amplifier, A5, which may be used for filtering, to provide additional gain, or for other applications. Supplied in 16-pin DIP's, with lead connections as identified in Fig. 1B, the LH0091 is available in two versions—one in a metal case, for the standard military temperature range (-55° to $+125^\circ$ C) and the other for commercial operation (-25° to $+85^\circ$ C).

A unique device, the LH0091 is, of course, but one of a substantial number of IC's developed specifically for test instrument applications. Special, as well as general-purpose IC's useful in test equipment designs, are available not only from National Semiconductor but from virtually all other solid-state device manufacturers, including AMI, Exar, Fairchild, Intersil, Motorola, Plessey, RCA, Signetics, Siliconix, and Texas Instruments.

Suitable for power supply and general purpose as well as test instrument applications, another National Semiconductor IC, the LM3999, looks deceptively like an inexpensive transistor, for it is assembled in a three-lead, type TO-92 plastic package. Despite its simple external appearance, however, the unit is a monolithic precision voltage reference which combines a multi-device temperature stabilizing circuit with a zener controlled regulator, as shown in its equivalent schematic diagram, Fig. 2A. Its pin connections are identified in Fig. 2B. In operation, the LM3999 behaves as a highly stable 6.95-volt zener diode with a low dynamic impedance of only 0.5 ohm and an effective current range from 0.5 to 10 mA. Accepting dc inputs from 9 to 36 volts, the separately powered stabilization circuit permits operation from 0° to $+70^\circ$ C with a temperature coefficient of $0.0005\%/^\circ\text{C}$ and a long term stability of 20 ppm. The circuit for a portable voltage calibrator circuit, one of the many possible test equipment applications for the LM3999, is given in Fig. 2C. Here, the LM3999 is used in conjunction with an LM312 operational amplifier. Supplying a precise 10-volt output level for equipment calibration, the instrument requires a warm-up time of ten seconds, but may be used intermittently without degradation of long term stability.

If your instrument project plans include one or more digital meters, you'll want to investigate yet another new National Semiconductor device, the DM7700, a monolithic IC which contains all of the active circuitry, except for display, needed for a $2\frac{1}{2}$ -digit meter. As illustrated by its simplified block diagram, Fig. 3A, the DM7700 comprises amplifier, reference voltage, voltage-to-frequency converter, clock, time-base, counter and latch circuits. Analog-to-digital conversion is



accomplished through the use of a dual voltage-to-frequency technique. One voltage-to-frequency converter generates a signal proportional to the input voltage while the other provides a sample window and determines the clock frequency for counting the output of the first. Requiring $+5$ - and -15 -volt dc sources for operation, the IC features a temperature compensated reference and both autopolarity and over-range output indicators. With an input impedance of 500,000 ohms, the device offers a full-scale analog range of ± 1.99 volts, a conversion time of 1 second, and an accuracy of $\pm 1.0\%$. Two versions of the IC are offered by the manufacturer, differing only in their temperature ratings. The standard DM7700 is specified for operation from -20° to $+95^\circ$ C, the less expensive DM8700 for operation from 0° to $+50^\circ$ C. Both versions are supplied in standard 24-pin double-width DIP's, with pin connections as identified in Fig. 3B, and both can provide adequate current drive for standard LED numeric displays. A typical application circuit for the DM7700 (or DM8700) is given in Fig. 3C. Except for the IC, the NSN-33 LED readout, and the dc power supply, the only components needed for operation are three capacitors, three fixed resistors, and two potentiometers.

After the multimeter and the oscilloscope, many technicians feel that the basic signal tracer is the next most valuable of bench service instruments. Essentially a self-contained audio amplifier with integral loudspeaker, the signal tracer can be used with appropriate accessory probes for checking radio and TV receivers, CB transceivers, intercoms, PA systems, tape recorders, record players, hearing aids, and stereo installations. The medium power audio amplifier IC's offered by many semiconductor manufacturers are ideal for assembling signal tracers. A typical circuit is shown in Fig. 4. Abstracted from a Fairchild Semiconductor (464 Ellis St., Mountain View, CA 94042) data sheet, the design features a type TBA800 monolithic audio amplifier IC. Assembled in a 12-pin power

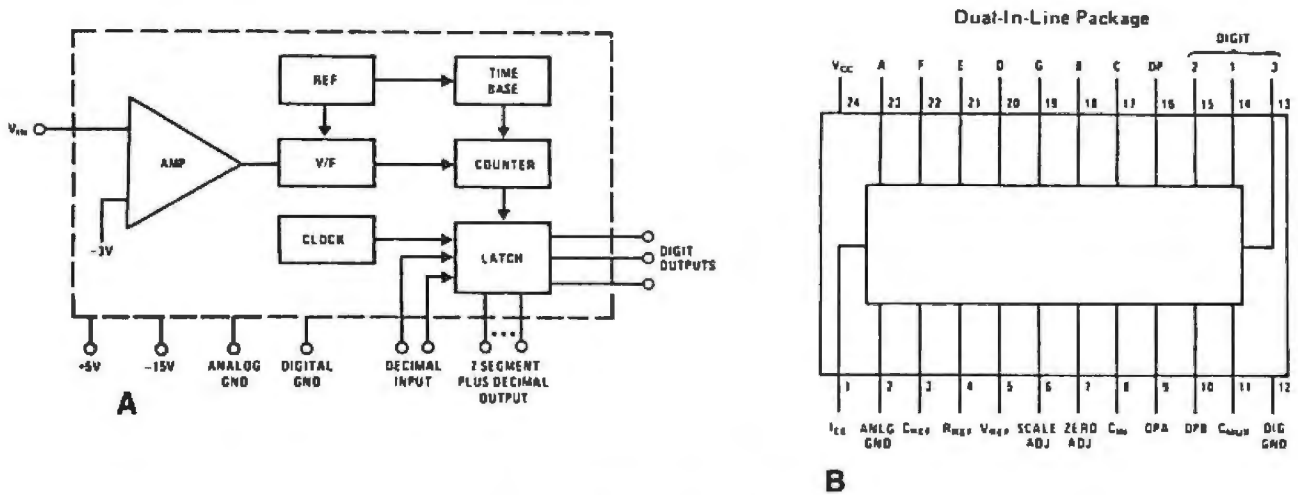


Fig. 3. Functional block diagram (A), lead connections (B), and typical application circuit (C) for DM7700 analog-to-digital meter converter integrated circuit.

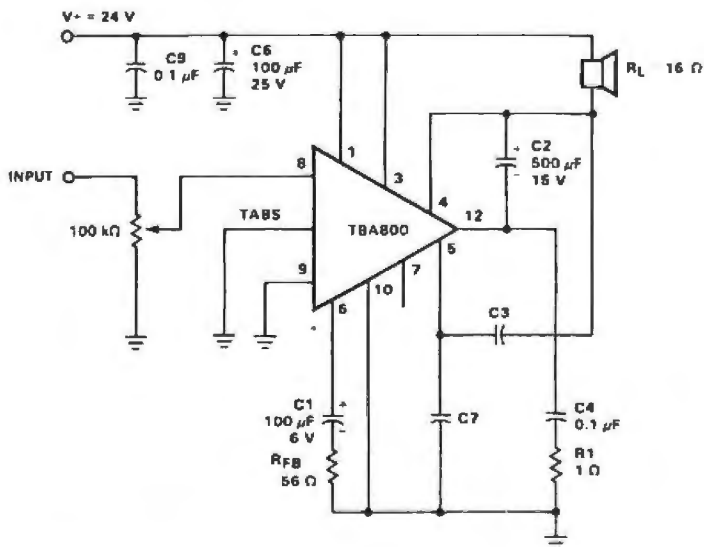
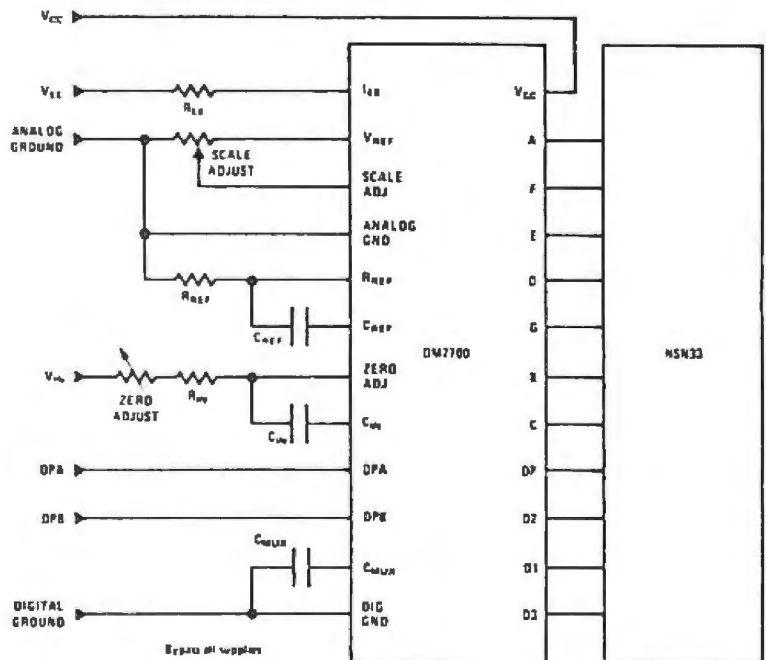


Fig. 4. With a TBA800 audio amplifier, this circuit can be used to make a basic signal tracer.

package with external cooling tabs, the TBA800 has a maximum voltage rating of 30 V and a maximum peak current capability of 2 A. With a modest heat sink, the device can deliver up to 5 watts to a 16-ohm load. At moderate output levels, the amplifier has a specified frequency response flat within 3-dB from 40 Hz to 20 kHz and an open-loop gain of 80 dB, with a typical total harmonic distortion of only 0.5%. Requiring but 80-mV input for full output, the IC's input resistance of 5.0 megohms permits it to accept all standard test probes. Properly matched to its load, the TBA800 is rated for 75.0% efficiency at full output. Referring to the schematic diagram, the circuit requires an external 24-V dc source for operation. This may be provided by batteries or by a well-filtered line-operated power supply, as preferred. All component values are specified except for C₃ and C₇, which are part of the compensation network. These capacitor values are chosen to provide the overall frequency response needed for the circuit's application. Generally, C₇ will be approximately five times as large as C₃. For most projects, C₃ can be a 330-pF low-voltage ceramic capacitor and C₇ a 1500-pF unit.

Although special-purpose IC's are ideal for instrument designs ranging from digital meters to multi-output function gen-

erators, operational amplifiers, as a broad class, are probably the most versatile of all IC's for general test equipment applications. Op amps may be used, typically, in sine-wave oscillators, pulse generators, oscilloscope preamps, active filters for signal analysis, bridge amplifiers, frequency meters, and staircase generators. Two representative examples of the many possible op amp test equipment circuits are given in Figs. 5 and 6. Both circuits were abstracted from application notes published by Intersil, Inc. (10900 N. Tantau Ave., Cu-

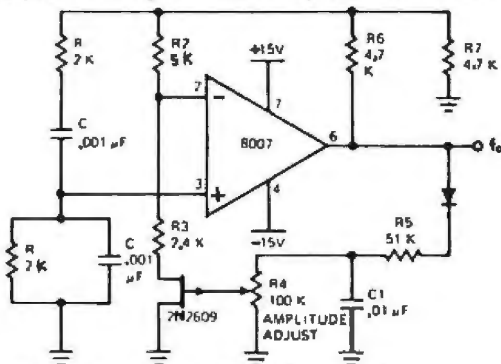


Fig. 5. Op amp Wein bridge oscillator described in an Intersil application note.

pertino, CA 95014), both feature FET-input op amps, and both are designed for operation on standard ± 15 -volt dual dc power sources.

Capable of delivering an output signal of 20 volts peak-to-peak, the Wein Bridge oscillator circuit shown in Fig. 5 may be used either alone as a test-tone source or as part of a complete audio-signal generator design. A type 8007 op amp serves as the basic oscillator, with a 2N2609 JFET used as a feedback element to provide amplitude control. In operation, the circuit's output frequency is determined by the values of the resistors and capacitors in the bridge feedback network and may be calculated from

$$f_0 = 1/2\pi RC,$$

where the frequency, f_0 , is in Hz, R is in megohms and C in μ F. Multiple output frequencies may be provided by using a number of different RC values, selected by means of a suitable multiposition switch. Continuous frequency coverage within a broad range can be obtained by replacing the two fixed resistors in the feedback network with a matched-pair gang potentiometer. The two techniques can be combined, of course, with switch selectable capacitors establishing different ranges and continuous coverage within each range provided by the ganged potentiometers.

Suitable for use in a variety of test equipment designs from counters to characteristics curve analyzers, the staircase generator circuit illustrated in Fig. 6 develops a cyclic stepped output signal waveform. Its active device complement includes a type 8043 dual op amp, a pair of low-leakage diodes, a type 1H5042 CMOS analog switch, and a type 311 voltage comparator. In operation, a high-frequency clock (square-wave) signal is applied to the first op amp, half of an 8043. Amplified, this signal drives the second op amp, which, in turn, charges a 0.02- μ F capacitor in small steps through a pair of low-leakage diodes. The capacitor's instantaneous voltage level is continuously compared to an externally applied dc reference by the 311 voltage comparator. When the capacitor voltage reaches the preestablished level, the comparator applies a signal to close the analog switch, discharging the capacitor to end the cycle and reset the circuit. The relative time width of

each step is determined by the initial clock frequency while the number of steps per cycle and hence the cyclic rate is established by the dc reference voltage applied to the 311 comparator.

Looking to the future, the next major evolutionary step in test instrument design probably will be the increased use of microprocessors and memory circuits. The use of these devices will permit the development of a whole family of automatic test instruments . . . units capable of performing a broad series of tests and, perhaps, of even changing the test procedures on the basis of initial results. More sophisticated future instruments may even provide aural outputs, telling the service technician where a circuit defect is located and which component or device should be replaced.

Reader's Circuit. Faced with frequent power interruptions in his area and having electrical equipment which required special start-up procedures if the ac power was removed for more than a few seconds, reader John M. King (1194 Idylberry Road, San Rafael, CA 94903) devised the protective control circuit shown in Fig. 7. The control is designed to maintain power-line contact with the protected equipment for short intervals in the event of a power failure, but to disconnect the equipment if the failure period exceeds a preset limit.

As shown in the schematic diagram, line power is applied to the external equipment connected to the dual outlet (SO1) through the contacts of relay K1 which, in turn, is controlled by a solid-state sensing circuit. Step-down transformer T1 in conjunction with bridge rectifier RECT1 and filter capacitor C1 form a dc power supply for the control circuit. Equipment operation is initiated when pushbutton S1 is depressed, turning on SCR1 and energizing K1. With SCR1 conducting, a dc charge is maintained on C2 by current flow through blocking diode D1. Should a momentary power failure occur, SCR1 will continue to conduct until C1 is discharged below the SCR's maintenance voltage, holding K1 closed and permitting the immediate reapplication of power to the external equipment. Thereafter, the SCR will switch to a high impedance state,

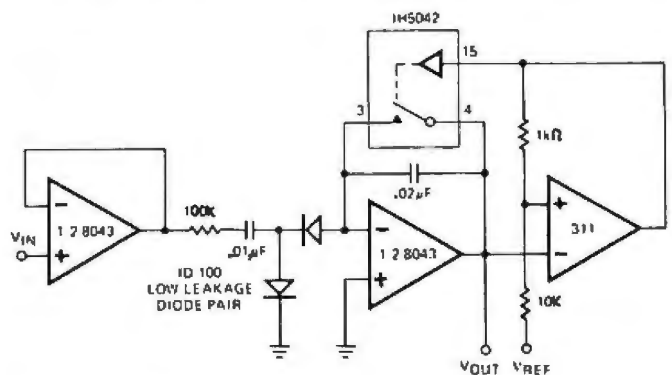
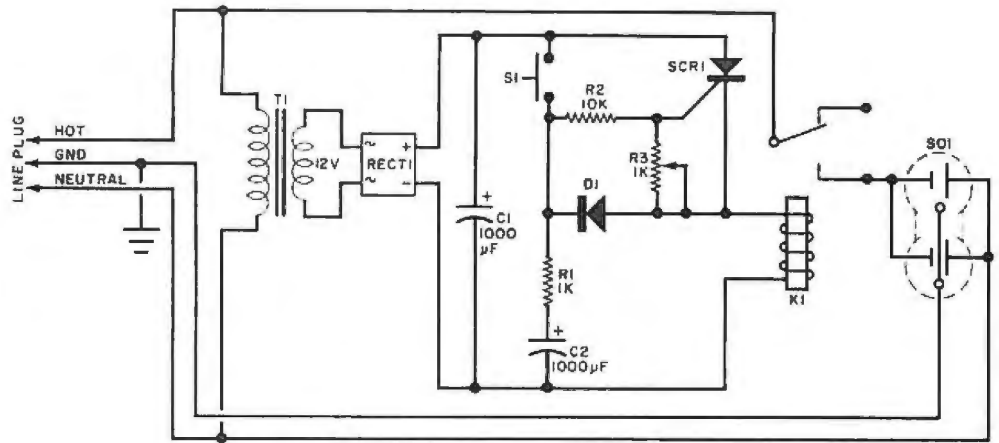


Fig. 6. Another Intersil circuit shown here is an op amp staircase generator.

opening the relay. However, a small gate voltage will be maintained on the SCR for a short while by the accumulated charge on C2. Thus, if ac line power is restored before C2 is discharged below the level needed to "fire" the SCR, circuit operation will be initiated automatically. If the power failure interval is longer than the time required for C1 and C2 to discharge, operation must be restarted manually by depressing S1, permitting the operator to carry out any necessary start-up procedures required by the protected equipment.

John used Motorola semiconductor devices in his design,

Fig. 7. This circuit maintains power-line contact during short power outages but will disconnect the equipment if failure exceeds a preset limit.



with the bridge rectifier a HEP type R0801, SCR1 a HEP type R1216, and diode D1 a HEP R0050. The step-down transformer may be any standard type with a 12-volt, 500-mA secondary. Resistors R1 and R2 are half-watt types. Capacitors C1 and C2 are 16-volt electrolytics. A 12-volt dc relay with a 95-ohm coil and contacts rated at 10 A is used for K1, while the control switch, S1, is a spst, momentary contact, NO pushbutton or lever type. Finally, the receptacle (SO1) is a familiar 3-wire dual wall outlet.

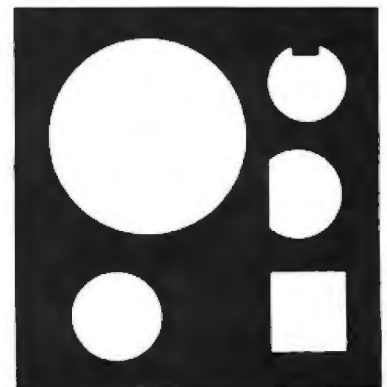
With neither layout nor lead dress critical, the circuit can be duplicated using any preferred construction technique but, for maximum safety, the wiring should be housed in a sturdy (and grounded) metal case or box. According to John, the time delay before manual resetting is required can be adjusted (by means of R3) between 1 and 12 seconds, which is more than adequate for most momentary power interruptions. If, for some reason, a longer delay is required, this may be achieved by increasing the values of C2, R2 and R3. Delays of up to a minute or two should be feasible with standard components.

Device/Product News. RCA's Solid State Division (Box 3200, Sommerville, NJ 08876) has added a new series of devices to its growing family of BiMOS (Bipolar/MOS) operational amplifiers, which feature MOSFET inputs and COS/MOS outputs. The new CA3160 series are frequency-compensated versions of the earlier CA3130 series op amps, and feature gate-protected p-channel MOSFET's in the input stage to provide input impedances of 1.5×10^{12} ohms (typical), very low input currents (5 pA typical at 15 V), and exceptional speed performance. In each, the output stage employs a complementary-symmetry MOS transistor pair capable of swinging the output voltage to within 10 mV of either supply voltage terminal, permitting direct interface with either CMOS or bipolar 7400 TTL series devices. Other features include wide bandwidth (15 MHz), high slew rate (10 V/ μ s unity-gain follower), and strobing capability to reduce standby power consumption. Suitable for applications in sample-and-hold amplifiers, long duration timers, wideband amplifiers, voltage followers, voltage regulators, Wein Bridge oscillators, VCO's, and photo-diode sensor amplifiers, the devices are offered in both standard and dual-inline formed 8-lead TO-5 packages.

In addition to its special purpose test instrument IC's, National Semiconductor has announced a new family of positive regulators with several fixed output voltages in three temperature ranges. Identified as the LM140LA series, the new devices have a 2.0% output voltage specification, 0.04%/volt line regulation, a 0.01%/mA load regulation, and can deliver up to 100 mA with adequate heat sinking. Offered in metal

TO-39 and plastic TO-92 packages, the new regulators are available with outputs ranging from 5.0 to 24.0 volts. All of the devices are protected by internal current limiting and thermal shutdown circuitry.

International Rectifier's Semiconductor Division (233 Kansas St., El Segundo, CA 90245) has recently introduced a pair of 900-volt npn transistors with power dissipation ratings of 50 watts. Designated types IR 708 and 709, the new units are suited for applications in video deflection circuits, high-voltage switching power supplies, power controls, and switching regulators. Both offer continuous collector current ratings of 3 A with fall times of 1.5 μ s, and both are supplied in standard TO-3 metal cases. \diamond



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