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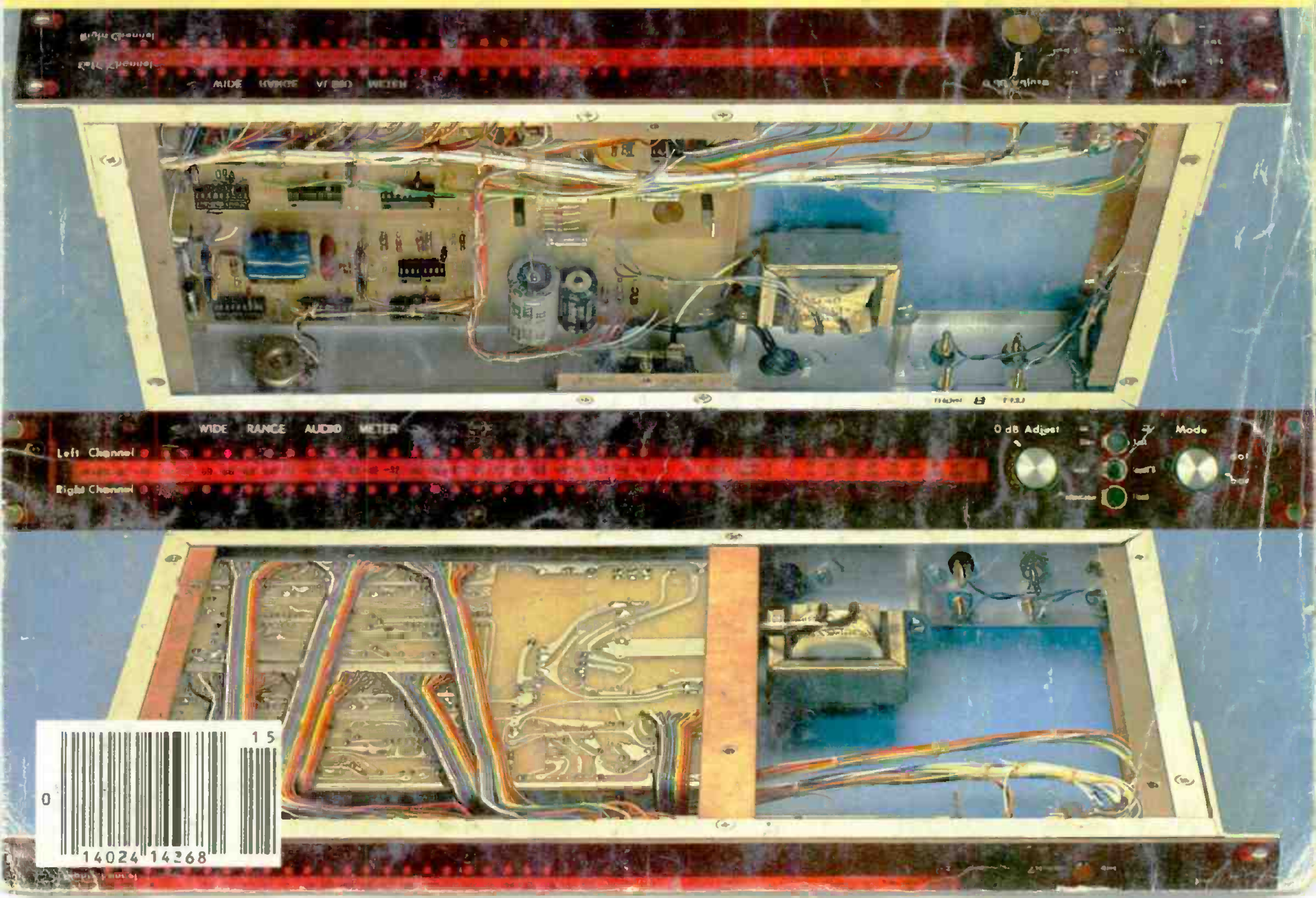

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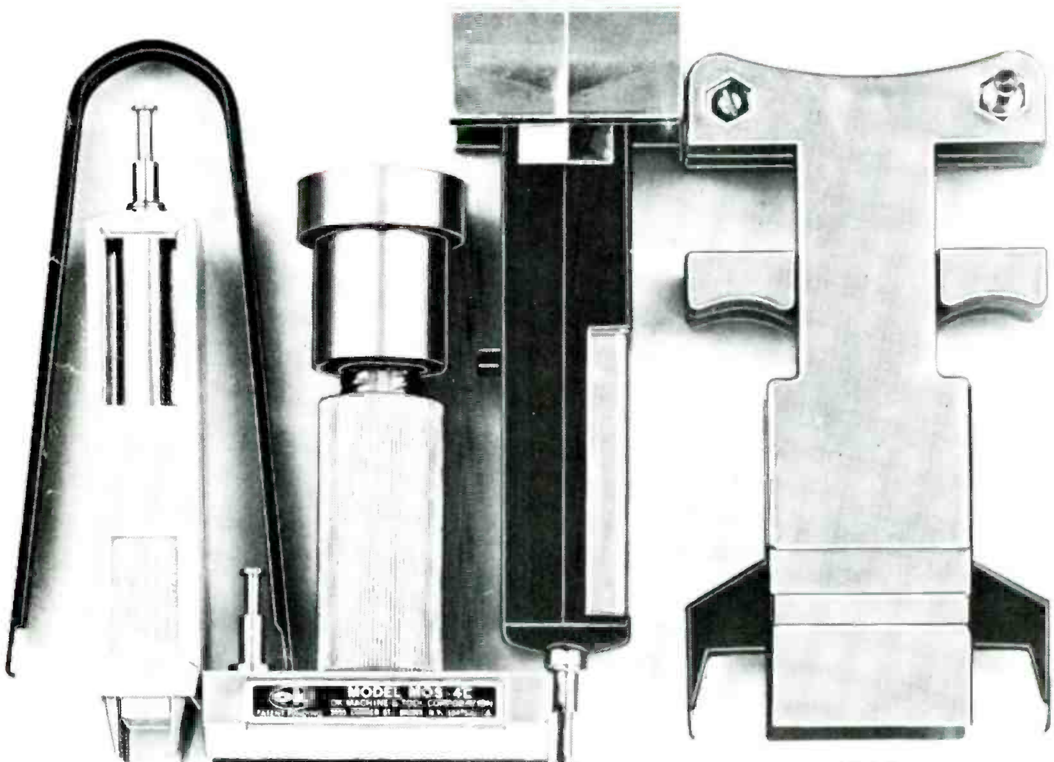

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CIRCLE NO. 9 ON FREE INFORMATION CARD

POPULAR ELECTRONICS

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COVER PHOTO: Barbara and Justin Kerr

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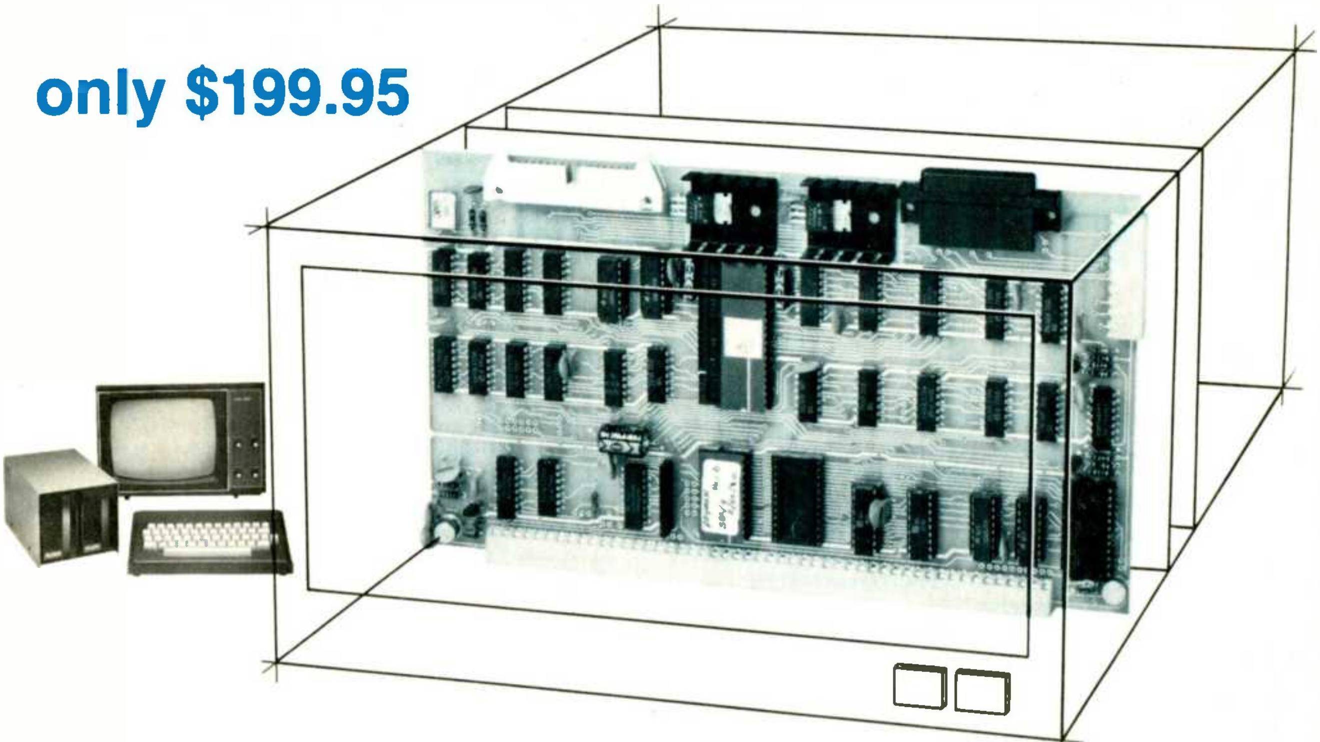

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CIRCLE NO. 11 ON FREE INFORMATION CARD

THE COVER

Shown is the front panel of a two-channel, wide-range audio-level meter that employs a LED readout. Mirror images above and below the front panel reveal the inside of the project. For information on how to build this high-performance but inexpensive monitoring unit, see our feature construction story. It begins on page 5.

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CIRCLE NO. 5 ON FREE INFORMATION CARD

KEEPING track of signal levels is a task that confronts most audio professionals and many amateurs as well. The ideal signal-level meter would have enough sensitivity to monitor the quietest of passages, yet would be able to respond instantly and accurately to high-amplitude transients without going off-scale and "pegging." Also, it would cover, using only one scale, the entire range of practical audio-signal levels. Presented here is the Wide-Range Audio Meter, a construction project that closely resembles the "ultimate" level monitor just described.

The Wide-Range Audio Meter is a high-performance, two-channel peak level monitor that provides a dynamic range from −84 to +3 dB with a display accuracy of ±1 dB. It employs strings of LEDs that function in either a moving-dot or bargraph mode (switch selectable) with 3-dB increments. Another switch permits selection of fast or slow display/decay time. Provisions are included for adjustment of the 0-dB reference over a range of 3.5 to 35 volts peak. In spite of the project's flexibility and impressive level of performance, it can be built for $100 or less.

Meter Basics. VU meters, although they have been audio workhorses for years, employ movements whose ballistic characteristics make them ill-suited for observing peak signal levels. They are also quite limited in dynamic range with their lowest 10 dB squeezed into the lower 10 percent of the scale.

A recent trend in audio equipment has been the use of optoelectronic signal-level displays either as supplements to traditional VU meters or as actual replacements for them. Substituting a solid-state, optoelectronic display circuit for a mechanical meter movement allows a designer to select practically any desired dynamic range, rise time, or averaging characteristic.

Perhaps the most popular device used in bargraph and moving-dot signal-level displays is the light-emitting diode. There are many reasons for the LED's popularity. A principal one is fast response time—a one-millisecond current pulse applied to a LED results in a light flicker that can readily be seen by the human eye. Secondly, because the LED is a low-voltage, relatively low-current device, it is compatible with integrated-circuit designs.

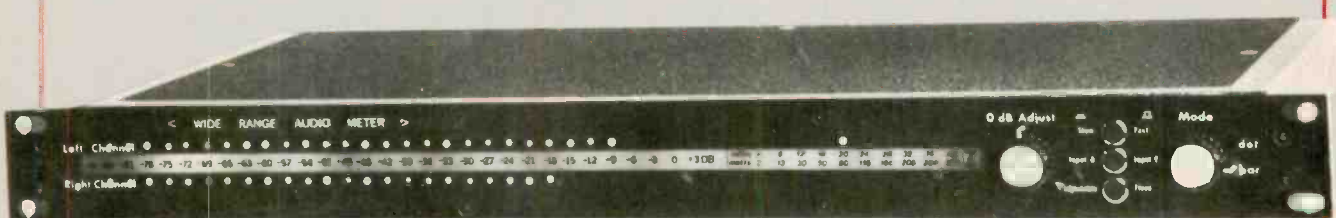
The LM3915 LED Driver IC. It is only in the recent past that new integrated driver designs for optoelectronic displays have emerged, thereby reducing circuit complexity. One of them is National Semiconductor's LM3915, an extremely versatile IC designed especially for driving bargraph and moving-dot LED displays. It accepts and processes an analog voltage applied to its input and has ten LED-driven outputs.

Each of the ten outputs corresponds to a 3-dB change in input level, for a total

Employs a LED moving-dot or bargraph display to indicate signal levels from -84 to +3 dB with adjustable 0-dB level.

BY FRAN HOFFART

BUILD A WIDE-RANGE AUDIO METER



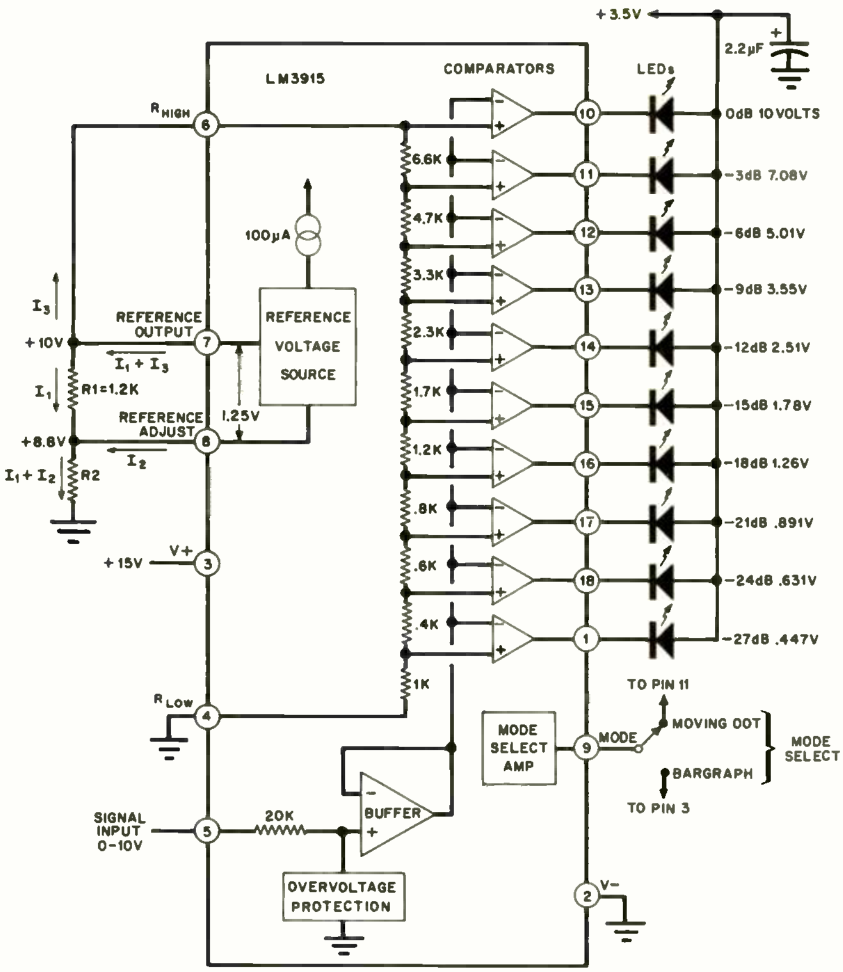


Fig. 1. Functional diagram of the LM3915 LED driver IC.

range of 30 dB. Each output can sink a regulated current that can be determined by selection of a single resistance value. The LM3915 includes a MODE pin by which the user can select either a moving-dot or bargraph display format. A built-in voltage reference, adjustable by means of external resistance values, can be used to drive an accurate, internal voltage divider. This divider, whose extremes are brought out to terminal pins, provides reference voltages to a string of internal comparators to control the outputs. Provisions are built into the LM3915 to allow several ICs of the same type to be cascaded for a total dynamic range of 60, 90, or even 120 dB. (However, additional gain stages are required if such high dynamic ranges are to be achieved.)

The LM3915 can be powered by a single-ended supply furnishing from +3 to +20 volts. Open-collector LED-driver outputs permit the use of a separate low-voltage power supply for the LEDs when the main supply voltage exceeds +5 volts. Powering the LEDs with a low-voltage supply, which can be unregulated or even unfiltered dc, results in greatly reduced IC power dissipation, especially when the display is functioning in the bargraph mode.

A functional diagram of the LM3915 driver IC appears in Fig. 1. Input signals

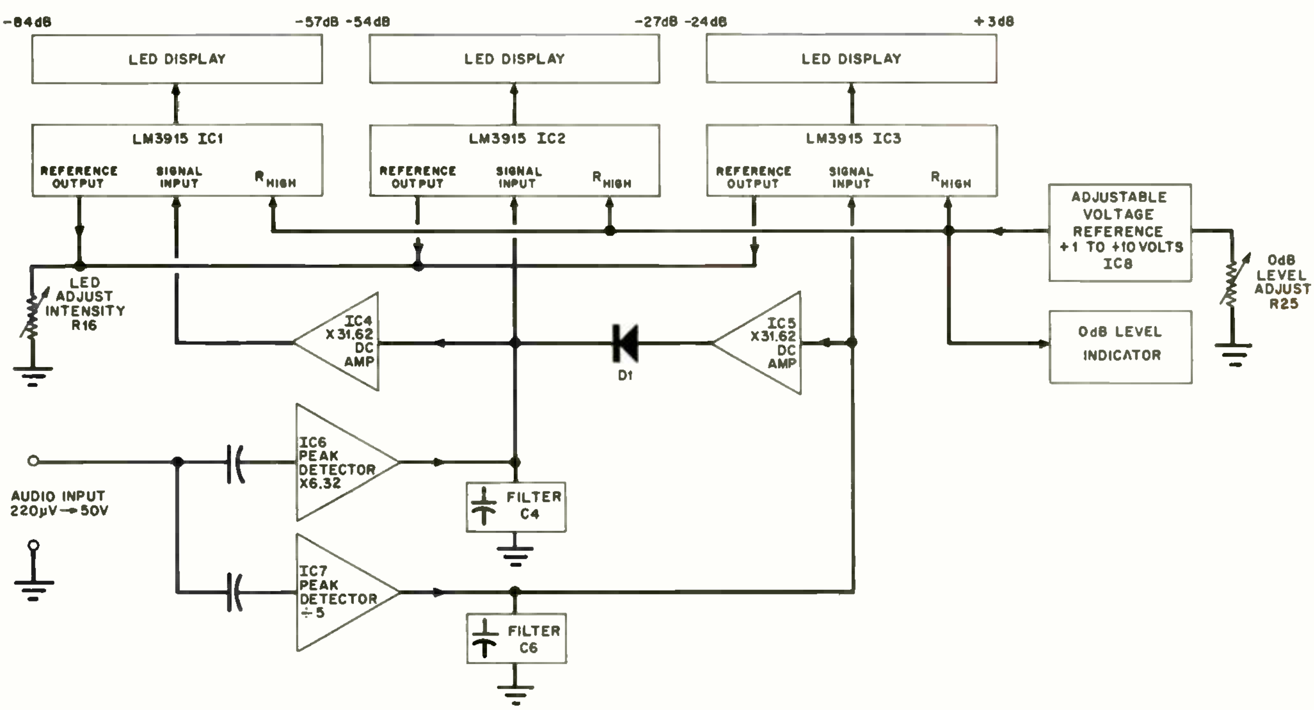


Fig. 2. Block diagram of one channel of the Wide-Range Audio Meter.

are buffered by a voltage follower with a very high input impedance, thereby minimizing loading of the signal source. The circuit as shown accepts input signals over a range of from +0.447 volt to +10 volts. It drives ten LEDs which correspond to 3-dB increments of input amplitude. The display format can be changed from a moving-dot to a bargraph format by means of the MODE SELECT switch. The small tantalum capacitor bypassing the LED supply bus prevents oscillations that can occur when the LED supply is unfiltered. Voltage of the main supply is not critical except that it must be well filtered and at least 1.8 volts more positive than the boosted reference voltage at pin 7, which is assumed in this description to be +10 volts.

The reference-voltage section of the circuit is very important to the overall operation of the LM3915 and of the circuits in which the device is used. An internal reference-voltage source forces pin 7, the reference output terminal, to be 1.25 volts more positive than pin 8, the reference adjust terminal. If pin 8 is grounded, the reference-voltage output will be +1.25 volts. Increasing the reference-voltage output is accomplished by placing a resistor *(R1)* between pins 7 and 8. This causes current *I1* to flow from pin 7. Current *I2*, a constant bias of approximately 100 μA, flows out of pin 8 and joins *I1*. These two currents combine and cause a voltage drop to appear across *R2*.

As a result, pin 8 becomes more positive by an amount equal to the voltage drop across *R2* and pin 7 becomes 1.25 volts more positive than the voltage between pin 8 and ground. Varying the value of *R2* causes the reference-voltage output to vary from a minimum of 1.2 volts to a maximum of 12 volts above ground. This voltage, which is very insensitive to changes in temperature and supply voltage, is usually used to drive the IC's internal voltage divider.

The current that flows through each lighted LED is approximately ten times the total current flowing out of pin 7, the reference output terminal. This current includes *I1*, the current used to boost the reference output voltage, as well as *I3*, the current drawn by the internal voltage divider. In the example circuit shown in Fig. 1, *I3* is fixed at 0.5 mA. The value of *R1* was selected to draw an additional 1 mA from the reference output, for a total of 1.5 mA flowing from pin 7. This causes the nominal current flow through each activated LED to be 15 mA. Currents *I1* and *I2* also boost the reference output to +10 volts.

Input signals applied to pin 5 are normally rectified, lightly filtered dc voltages. They range in amplitude from 0 to +10 volts, although the input stage can tolerate up to ±35 volts without damage. If unrectified, unfiltered audio is applied to the input of the LM3915, the LED display will be activated in such a way that it accurately tracks the input waveform. Peak signal levels, as well as the average amplitude, will readily be seen. A moving-dot will not be observed in the display in this case, even if the moving-dot mode has been selected. This is so because the circuit follows the signal from 0 volts up to its peak level with almost no delay, lighting each appropriate LED as it tracks the signal. The low-order LEDs will appear to be on constantly, even though they are quickly turning on and off.

About the Project. A block diagram of the Wide-Range Audio Meter is shown in Fig. 2. This project employs three cascaded LM3915s to display the signal levels present in one audio channel over a 90-dB dynamic range. A string of 30 LEDs is employed to display the input amplitude in 3-dB increments. The 0-dB signal level can be adjusted over a 20-dB range by means of a potentiometer. The user can select either a moving-dot or bargraph display format, as well as a fast or slow display decay time. A peak input amplitude of 50 volts was chosen as the level required to light the highest-order (+3-dB) LED, but this can be readily altered by changing a few resistance values.

A glance at the block diagram reveals that the same reference voltage (+10 volts) is applied to each IC's voltage divider. This means that a signal amplitude of +10 volts must be present at the input of any of the LM3915s for its highest-order LED to glow. To produce the appropriate input level for a specific LM3915, the audio input signal is either amplified or attenuated.

The basic operation of the project is as follows. Audio input signals from 220 μV to 50 volts peak amplitude are simultaneously coupled to peak detectors *IC6* and *IC7*. These stages not only accurately rectify the signal but also provide level matching—amplification in the case of *IC6*, attenuation in the case of *IC7*. Two peak detectors, each covering a specific range of input signal levels, are employed because of the project's wide dynamic range. Audio signals from 50 volts peak down to 1.58 volts peak are rectified and attenuated by *IC7* by a factor of 5 so that the proper 10-to-

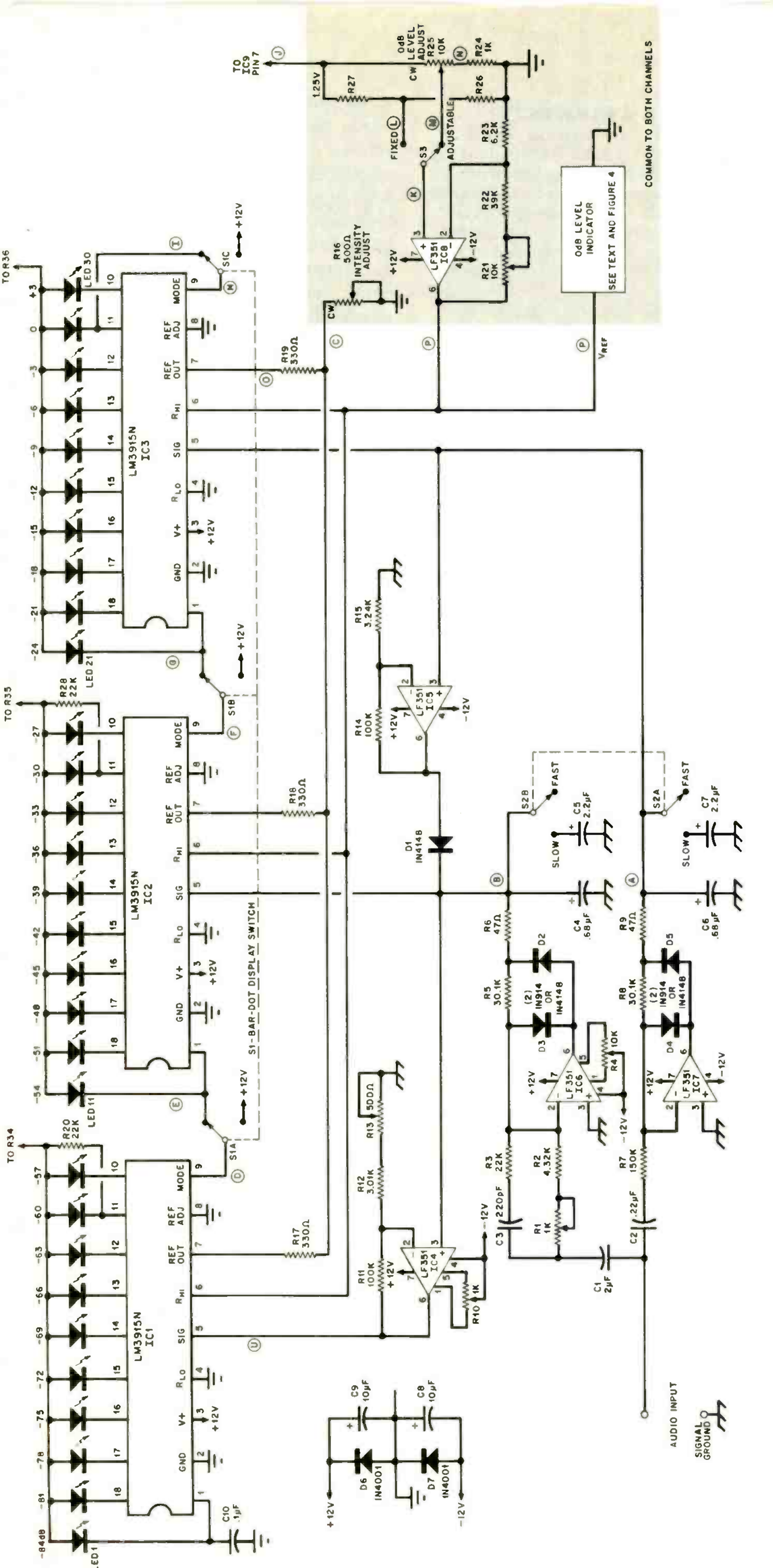
PARTS AVAILABILITY

The following are available from FJH Electronics, Box 62254, Sunnyvale, CA 94086: Etched and drilled printed-circuit board, all required integrated circuits and all required 1%-tolerance metal-film and 5%-tolerance carbon-film resistors for $64 plus $3 postage and handling within the continental U.S.; etched and drilled printed-circuit board only for $26 postpaid. California residents add 6.5% state sales tax.

0 dB LEVEL INDICATOR

(Levels correspond to LEDs driven by LM3914s)

	Peak signal level across audio input terminals required to light 0-dB LED		*V_{REF} Adjustable via R25*
LED	**Peak Voltage**	**Peak Power (8Ω resistive)**	**(Test Point P)**
	(Volts)	(Watts)	(Volts)
LED40	40	200	—
LED39	36	162	10.18
LED38	32	128	9.05
LED37	28	98	7.92
LED36	24	72	6.79
LED35	20	50	5.66
LED34	16	32	4.53
LED33	12	18	3.39
LED32	8	8	2.26
LED31	4	2	1.13



MAIN PARTS LIST
(ONE CHANNEL ONLY)

C1—2.0-μF Mylar capacitor (see text)
C2—0.22-μF Mylar capacitor
C3—220-pF disc ceramic capacitor
C4, C6—0.68-μF, 35-volt tantalum capacitor
C5, C7—2.2-μF, 35-volt tantalum capacitor
C8, C9—10-μF, 25-volt electrolytic capacitor
C10—0.1-μF disc ceramic capacitor
D1 through D5—1N914 or 1N4148 silicon signal diode
D6, D7—1N4001 silicon rectifier
IC1, IC2, IC3—LM3915N logarithmic level detector/LED driver
IC4 through IC7—LF351N BiFET op amp
IC8—LF351N BiFET op amp (only one required for two-channel project)
LED1 through LED30—Red light-emitting diode (NSL5086 or equivalent)
The following are ¼-watt, pc-mount linear-taper trimmer potentiometers.
R1, R10—1 kΩ
R4—10 kΩ
R13—500 Ω
R21—10 kΩ (only one required for two-channel project)
The following are ¼-watt, 1%-tolerance, metal-film fixed resistors.
R2—4.32 kΩ
R5, R8—30.1 kΩ
R7—150 kΩ
R11, R14—100 kΩ
R12—3.01 kΩ
R15—3.24 kΩ
R26, R27—These components determine the fixed 0-dB reference level, and their values should be selected for the particular level desired. Only one of each is required for the two-channel project.
The following are ¼-watt, 5%-tolerance, carbon-film fixed resistors.
R3, R20, R28—22 kΩ
R6, R9—47 Ω
R17, R18, R19—330 Ω
R22—39 kΩ (only one required for two-channel project)
R23—6.2 kΩ (only one required for two-channel project)
R24—1 kΩ (only one required for two-channel project)
The following are panel-mount, linear-taper potentiometers.
R16—500 Ω (only one required for two-channel project)
R25—10 kΩ (only one required for two-channel project)
S1—6pdt push-on/push-off switch (only one required for two-channel project, three poles used for each channel)
S2—4pdt push-on/push-off switch (only one required for two-channel project, two poles used for each channel)
S3-Spdt push-on/push-off switch (only one required for two-channel project)
Misc.—Printed-circuit board, IC sockets or Molex Soldercons, suitable enclosure, dry-transfer rub-on lettering, ribbon cable, hook-up wire, suitable input jacks or terminals, solder, hardware, etc.

Fig. 3. Schematic diagram of the Wide-Range Audio Meter. Only one channel of the signal-processing and display circuits is shown.

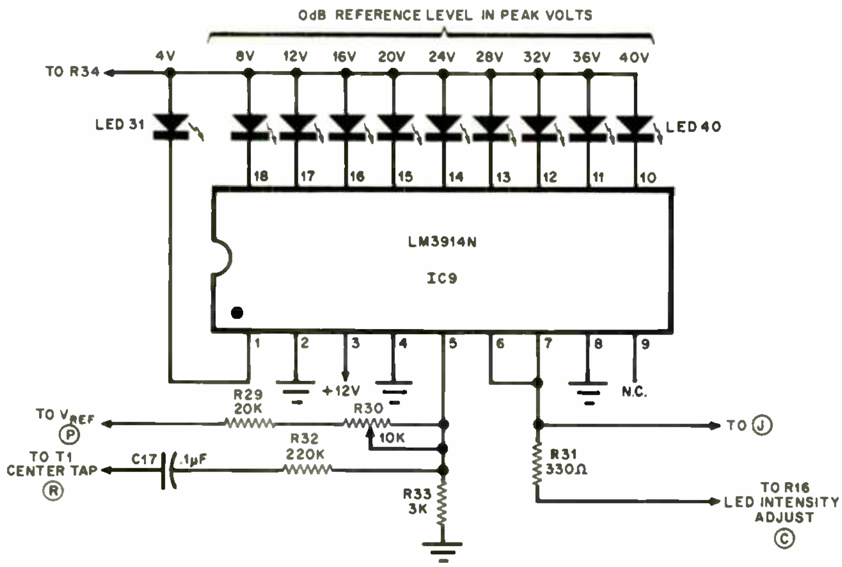


Fig. 4. Schematic diagram of the project's 0-dB Level Indicator.

0-dB LEVEL-INDICATOR PARTS LIST

(Only one of each component required for one- or two-channel audio meter project.)

C17—0.1-µF Mylar or disc ceramic capacitor
LED31 through LED40—Red light-emitting diode (NSL5086 or equivalent)
IC9—LM3914N linear level detector/LED driver
The following are ¼-watt, 5%-tolerance, carbon-film fixed resistors unless otherwise specified.
R29—20 kΩ
R30—10 kΩ, pc-mount linear-taper trimmer potentiometer
R31—330 Ω
R32—220 kΩ
R33—3 kΩ

0.316-volt range of input levels for LED driver *IC3* is achieved. Signals below 1.58 volts peak are rectified and amplified by *IC6* by a factor of 6.32. The dc output of *IC6* is applied to the input of LED driver *IC2* and to the input of amplifier *IC4*, which boosts the output of *IC6* by a factor of 31.62 to the level required by LED driver *IC1*.

Capacitors *C4* and *C6* filter the rectified audio signals, and in part determine the attack and decay times (the "ballistics") of the LED display. Because the project is intended for peak-monitoring applications, the display's attack time must be quick. It can be lengthened by increasing the appropriate RC time constant. A separate time constant, which is switch selectable (slow or fast), determines the display's decay time.

If the dc reference voltage applied to the voltage divider in each LM3915 is reduced from +10 volts to +1 volt, the sensitivity of the LED display will increase by a factor of 10. Now, a peak input signal voltage of only +5 volts will cause the highest-order (+3-dB) LED to glow. Operation at such a lower reference voltage will degrade the project's accuracy somewhat, but careful calibration can minimize any error.

The reference voltage applied to the internal divider of each LM3915 is adjustable over a +1-to-+10-volt range by means of potentiometer *R25*. This results in a "sliding" 0-dB signal level which can be adjusted for optimum results in signal-to-noise and peak-level measurement applications.

Amplifier *IC5* performs the following function. Under normal conditions, when the level of the input signal is close to the 0-dB level, the output of amplifier *IC6* is saturated at approximately the voltage on the +12-volt supply rail. The voltage across filter capacitor *C4* is held at approximately +11 volts by *IC6*. At the same time, the voltage across *C6* is

POWER SUPPLY PARTS LIST

C11—500-µF, 25-volt electrolytic capacitor
C12—2200-µF, 25-volt electrolytic capacitor
C13—0.22-µF Mylar or disc ceramic capacitor
C14, C15, C16—10-µF, 25-volt electrolytic capacitor
D8, D9, D10—1N4001 silicon rectifier
D11—1N914 or 1N4148 silicon signal diode
F1—¼-ampere slow-blow fuse
IC10—LM340T-12 or LM341MP-12 +12-volt regulator
IC11—LM320T-12 or LM320MLP-12 −12-volt regulator
R34, R35, R36—10 Ω, ½-watt, 5%-tolerance carbon-composition fixed resistors
T1—12.6-volt, 1.2-ampere center-tapped transformer (Radio Shack 273-1505 or equivalent)
Misc.—Fuse holder, line cord, strain relief, etc.

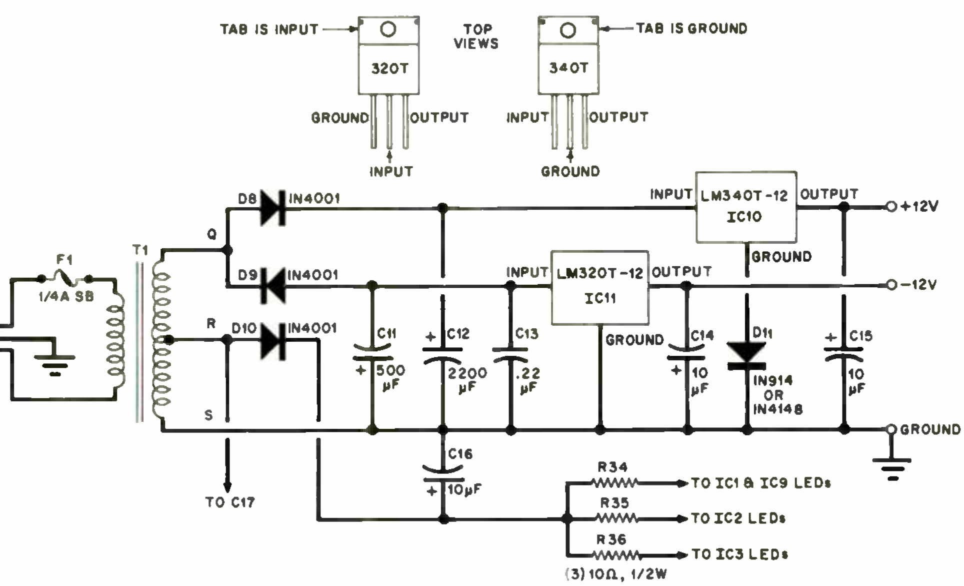
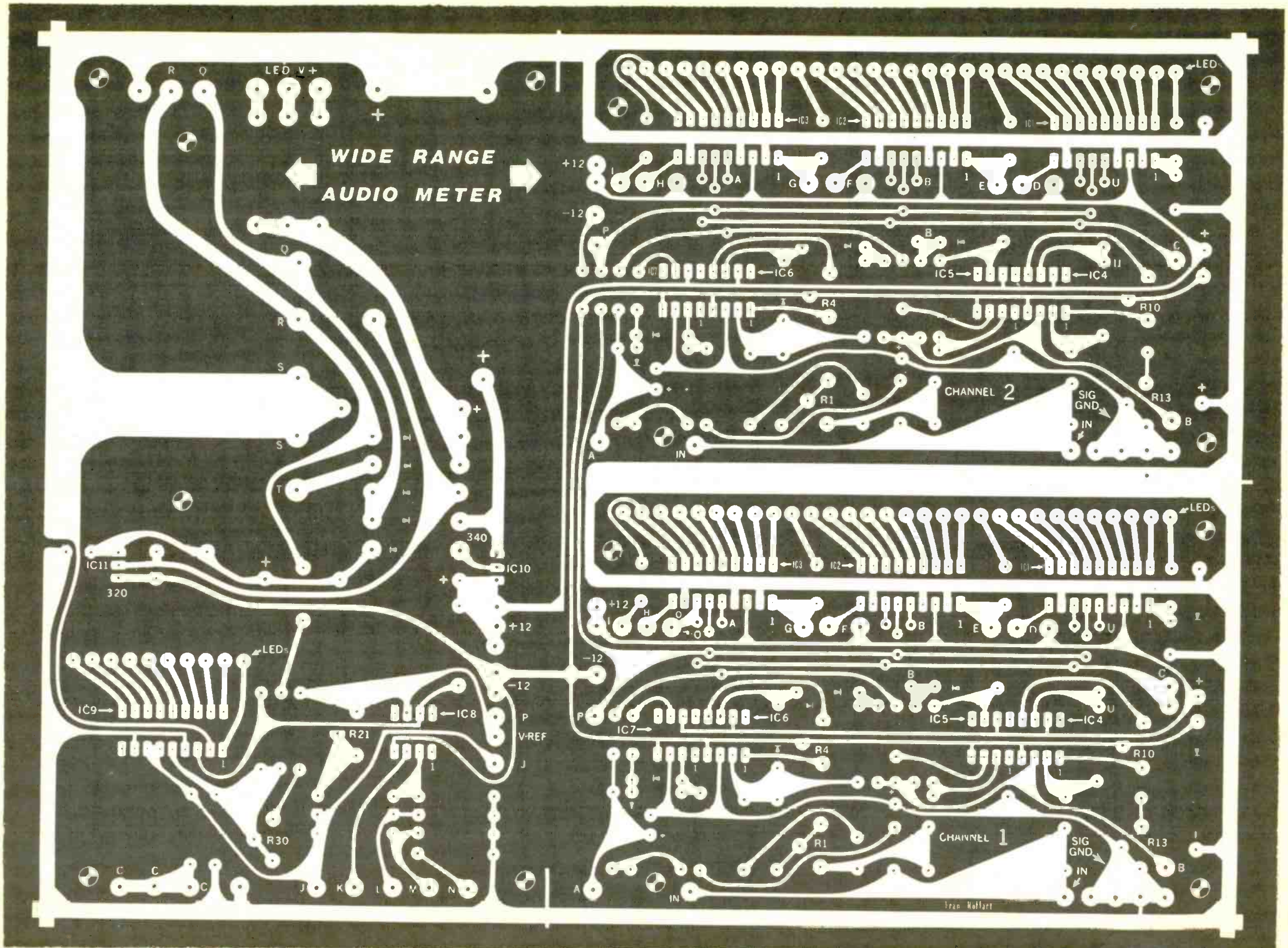


Fig. 5. Schematic diagram of the supply that satisfies the power requirements of a two-channel version of the Wide-Range Audio Meter.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CHANNEL 2
SIG GND
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+12
-12
IC1
IC2
IC3
IC4
IC5
IC6
IC7
IC8
IC9
IC10
IC11
320
340
R1
R4
R10
R13
R21
R30
LEDs

changing from 0 to +10 volts, depending on the amplitude of the audio input signal. In the event of a sudden decrease in input-signal level, were it not for the action of *IC5*, both filter capacitors (*C4* and *C6*) would begin to discharge immediately and simultaneously. This would cause the center group of 10 LEDs (those controlled by *IC2*) to begin "ramping" downward before the right group of 10 LEDs (those controlled by *IC3*) have had a chance to "ramp" down completely, that is, to extinguish completely. Amplifier *IC5* eliminates this problem by maintaining the voltage across *C4* at approximately +11 volts until the potential across *C6* has decayed to approximately +0.5 volt. When this happens, diode *D1* becomes reverse-biased, and rectifier/amplifier *IC6* regains sole control over the charg-

Fig. 6 (opposite page). Full-size etching and drilling guide for the project's printed circuit board.

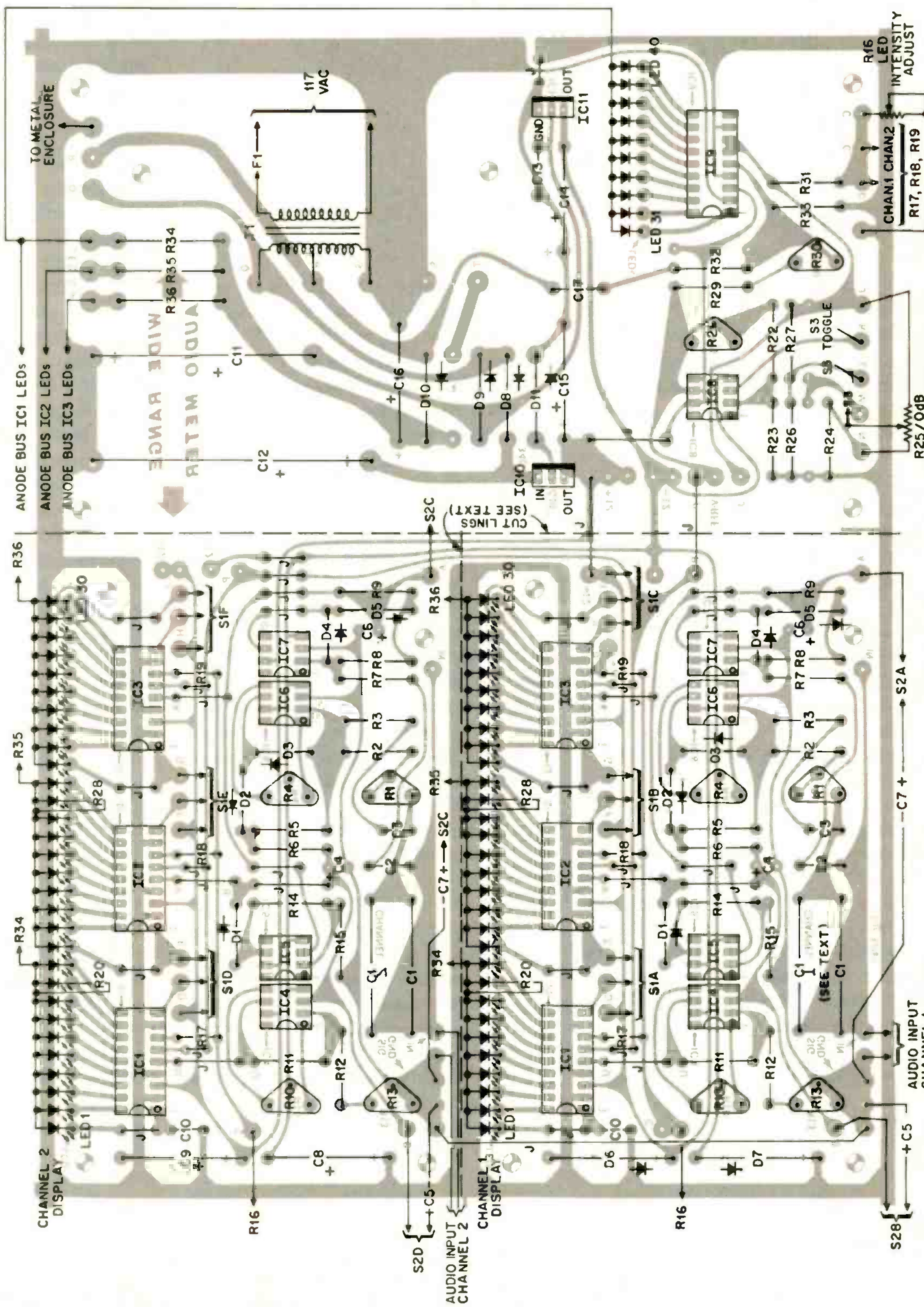


Fig. 7. Component-placement guide for the project's printed-circuit board.

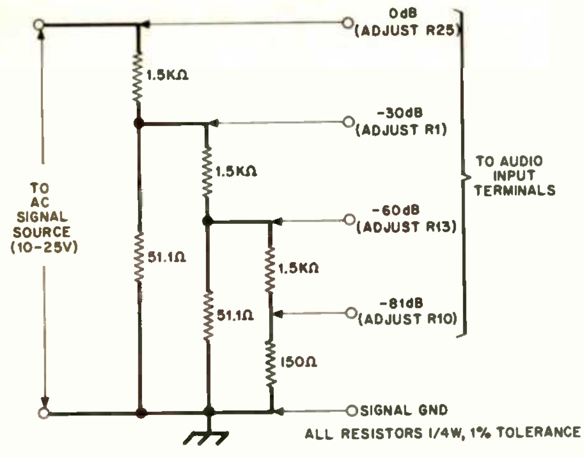


Fig. 8. Schematic diagram of a precision voltage divider suitable for project-calibration purposes.

ing and discharging characteristics of filter capacitor *C4*.

Also appearing in the block diagram of Fig. 2 is a 0-dB indicator stage. It is designed around the National Semiconductor LM3914 LED driver IC, which is closely related to the LM3915. The principal difference between the two lies in the configuration of the internal voltage dividers and the resulting input/output responses. As was mentioned earlier, the divider in the LM3915 causes the outputs to have a logarithmic response—an increase in input-signal level of 3 dB causes the next-higher-order LED driver to become activated. The LM3914, on the other hand, has a linear input/output response—a 1-volt change in input level (say, from +3 to +4 volts) causes the next-higher-order LED driver to sink current.

The 0-dB level-indicator monitors the reference voltage applied to LM3915 LED drivers *IC1*, *IC2* and *IC3* and activates a 10-LED moving-dot display that indicates to the user what signal level has been selected as 0 dB by the adjustment of potentiometer *R25*. The 1.25-volt reference required by reference amplifier *IC8* is supplied by *IC9*, the LM3914 LED driver in the 0-dB level-indicator circuit.

The LM3914 drives LEDs that glow to indicate the selection of a 0-dB level corresponding to a voltage between 4 and 40 volts. The LED display has 4-volt increments, but these are too large for this application. A method is employed that provides gradual turn-on and turn-off of the LEDs as the dc voltage that is being monitored changes. This scheme, called *dithering*, allows the user to easily resolve a 1-volt change in the 0-dB reference level.

Dithering works as follows. A small 60-Hz ac signal is superimposed on the dc level set up by the 0-dB adjust potentiometer. This allows adjacent LEDs to be proportionally on, depending on the exact amplitude of the dc level. If the 20-volt and 24-volt LEDs glow with equal intensity, for example, the display will indicate that the 0-dB level is 22 volts. If the 24-volt LED is brighter than the 20-volt LED, the 0-dB level will be 23 volts. Finally, of course, if only the 24-volt LED is glowing, the 0-dB level will remain at 24 volts.

The schematic diagrams of one channel of the Wide-Range Audio Meter and of the 0-dB level-indicator circuit appear in Figs. 3 and 4, respectively. That portion of Fig. 3 which is shaded represents circuits that are common to both audio channels. Switch *S1* allows the user to select either the moving-dot or bargraph display format, and *S2* permits selection of either a fast or slow display decay time. Note that two separate ground symbols are used. The traditional earth-ground symbol represents the ground used by the high-level circuits in the project, and the chassis-ground symbol represents signal ground. Special grounding precautions must be taken to prevent ground loops which would adversely affect the low-level and high-gain stages of the project.

Capacitive coupling at the audio input eliminates spurious readings that might occur if the signal source's output has a dc level offsetting it from ground potential. A nonpolar 2-μF capacitor is used for input coupling and determines the low-frequency response of the meter. For the value specified, the meter's response is down 3 dB at 15 Hz. The exact value of nonpolar capacitance specified for use as coupling capacitor *C1* might not be readily available. In light of this, provisions are included on the printed-circuit board (Fig 6) for the use of two 1-μF Mylar capacitors which are connected in parallel.

Some details of the 0-dB level-indicator circuit are worthy of mention. The LM3914's internal voltage divider is driven by the chip's own +1.25-volt reference source. Therefore, the LM3914 functions as a linear, moving-dot voltmeter with a full-scale reading of +1.25 volts. Resistors *R29*, *R30* and *R33* scale down the dc voltage appearing on the main meter circuit's V_{REF} line to a level suitable for processing by LED driver *IC9*. The voltage-dividing action of components *C17*, *R32* and *R33* provides a small 60-Hz signal that is impressed upon the dc level to be monitored for the dithering discussed earlier. A chart showing the relationship between the reference voltage applied to the LM3915s and the corresponding 0-dB levels in peak voltage and peak power levels (peak watts dissipated by an 8-ohm resistive load) appears in the Table on page 7.

The power requirements of the Wide-Range Audio Meter circuits for two audio channels and of the 0-dB level-indicator circuit can be satisfied by the supply shown schematically in Fig. 5. This power supply furnishes a regulated bipolar 12-volt output for the signal-processing stages as well as an unregulated, half-wave-rectified, lightly filtered dc output that is used to power the display LEDs. The transformer that is specified as *T1* in the parts list was used in the construction of the author's prototype, and substitution of another transformer should not be casually made for the following reason.

Under light-load conditions, many 12.6-volt transformers will generate 14 to 15 volts across their secondaries. If a particular transformer does not provide somewhat more than 12 volts, it might not be able to supply enough voltage to keep voltage regulators *IC10* and *IC11* functioning properly. If this is the case, the transformer can be modified by adding additional turns to the secondary winding, or an additional low-voltage transformer can be connected to it to increase the voltage available to the regulator inputs.

Construction. Because circuit layout is critical in the low-level stages of the project, the use of printed-circuit construction techniques is recommended.

The full-size etching and drilling guide for a pc board that has been carefully laid out for maximum circuit performance is shown in Fig. 6. This board can accommodate two channels of audio-level monitoring, the 0-dB level-indicator circuit, and the suggested power supply. The author mounted his prototype in a homemade enclosure with dimensions that made it suitable for 19-inch rack mounting. This explains the relatively large size of his printed-circuit board. However, the author recognized that some readers would probably prefer to assemble the project using a more compact enclosure. For this reason, he has included a set of dotted lines in the circuit board's etching and drilling guide. The board can be cut along these lines into three smaller boards, and, using suitable standoffs, the boards containing the channel 1 and channel 2 metering circuits can be stacked one on top of the other. However, if the board is cut up into three smaller boards, the ± 12-volt supply lines, the V_{REF} foils, and the ground lines must be interconnected using suitable lengths of flexible, stranded hookup wire.

Most of the components comprising the project are mounted on the printed-circuit board. The major exceptions are the display LEDs, the 0-dB LEVEL ADJUST and LED BRIGHTNESS ADJUST potentiometers, switches *S1* through *S4*, resistors *R20* and *R28*, and capacitors *C5* and *C7*. The capacitors are mounted on the lugs of display-decay selector switch *S2*. Transformer *T1* can be mounted on the circuit board if there is sufficient clearance for it inside the project enclosure. If not, its location is not critical provided that it is not placed too close to the low-level audio-input stages and it is oriented for minimum induction of hum onto signal-carrying leads and foils.

The use of Molex Soldercons or IC sockets is highly recommended for all integrated circuits except the voltage regulators. One-percent tolerance, metal-film resistors are specified for use in all critical gain-determining portions of the project. If it is impossible to locate 1%-tolerance resistors, good-quality 5%-tolerance components can be used with some loss in calibration accuracy.

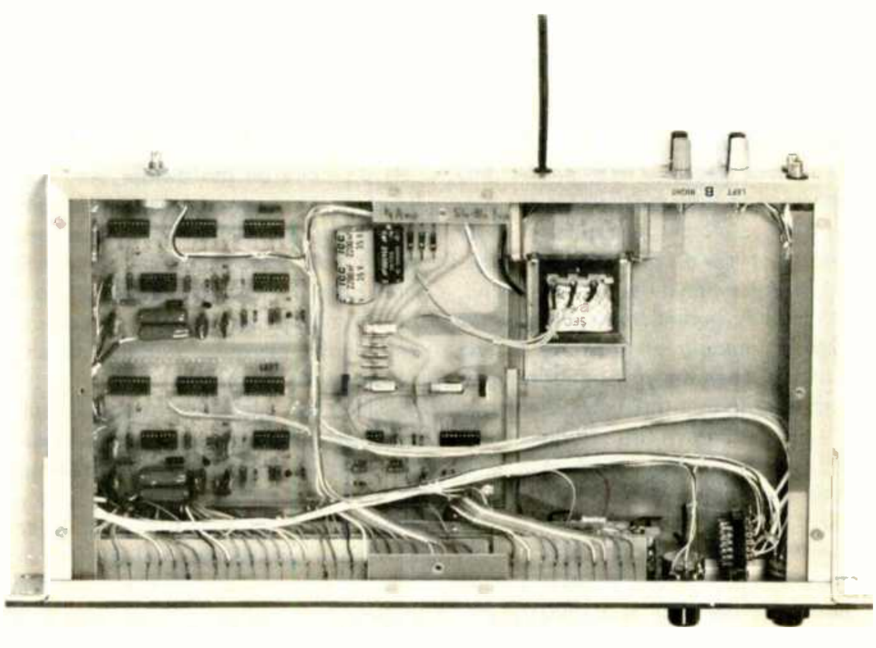
After the printed-circuit board has been completely wired, it can be mounted in a suitable enclosure and interconnected with the various switches and controls and the array of 70 light-emitting diodes. One acceptable method of mounting the LEDs is to employ a long, narrow strip of single-sided printed-circuit board. The board can provide mechanical support and an electrical contact for the LEDs' anodes. To do this, position the LEDs so that they are straddling the pc board and their anode leads are on the foil side of the board. The anode leads should be soldered to the foil, which becomes a positive bus, and the cathode leads should be soldered to suitable lengths of hook-up wire that run to the appropriate pads on the main project pc board. Flat, multiconductor ribbon cable is well suited for this latter application.

The foil on the LED pc board can be cut to electrically isolate the anodes of one group of ten LEDs from the next. However, before soldering any of the LEDs, make sure it is properly oriented with respect to polarity, that it lines up properly with its front-panel cutout, and that its body is somewhat removed from the long, narrow pc board. This last precaution is due to the heat sensitivity of a LED's plastic body. Finally, don't forget to include resistors *R20* and *R28* on the LED assembly. They are in parallel with *LED9* and *LED19*, respectively.

If only a bargraph or moving-dot display format is desired, MODE switch *S1* is not needed. If it is omitted, wire jumpers should be installed on the main pc board from each LM3915's MODE terminal (pin 9) to the +12-volt supply or to points E, G, and I, as the case may be. Switch *S3* allows the user to select either a fixed reference voltage or a variable one determined by the setting of potentiometer *R25*. If this flexibility is not desired, switch *S3* can be omitted if a jumper is connected between test point *K* and either test point *L* or the wiper of potentiometer *R25*.

Special precautions must be taken when assembling the input-signal circuit paths. Noise pickup and ground loops can easily degrade the project's useful dynamic range if careful circuit-layout techniques are not followed. A wire jumper is used to connect the signal grounds of the two audio channels together, represented by the traditional earth-ground symbol, to the high-level ground, represented by the chassis-ground symbol, at one and only one point. The project's metal enclosure should be connected to high-level ground at one point only. Twisted-pair wiring should be used in the audio-input paths, but kept away from the power transformer to minimize hum and noise problems.

Checkout and Calibration. After you have checked the circuit wiring thoroughly, you can apply ac power to the project. A sensitive, accurate dc voltmeter and an ac source are the only items of test equipment needed. Monitor the power supply outputs with the voltmeter. Output voltages should be as follows: approximately −12 volts at the output of *IC11*, +12.6 volts at the output of *IC10*, and approximately +3.5 volts across filter capacitor *C16*. If the correct voltage polarities and magnitudes



This photograph of the author's prototype reveals construction details.

appear, the project is ready for the calibration procedures.

The precision resistive voltage divider shown schematically in Fig. 8 should be constructed before the calibration procedure is begun. Constructing this divider eliminates the need to procure an accurate ac voltmeter for calibration purposes. The four calibration steps are as follows.

• ***Reference Voltage Calibration.*** Place *S3* in its ADJUSTABLE position and rotate the shaft of 0-dB LEVEL ADJUST potentiometer *R25* to its fully clockwise position. With the probes of the dc voltmeter connected to test point P and high-level ground, adjust trimmer potentiometer *R21* for a voltage reading of +10.18 volts. Rotating the shaft of 0-dB LEVEL ADJUST potentiometer *R25* to its fully counterclockwise position will decrease the voltage between test point P and high-level ground to approximately +1 volt.

• ***0-dB Level Indicator Calibration.*** Rotate the shaft of 0-dB LEVEL ADJUST potentiometer *R25* fully clockwise until the voltage between test point P and high-level ground again equals 10.18 volts. Next, adjust trimmer potentiometer *R30* so that only *LED39* (representing a 0-dB reference level of 36 volts) glows. If the adjacent LEDs will not extinguish completely, the ac dithering voltage is too large. This can be corrected by replacing *R32* with a resistor having the next larger value.

• ***Op-Amp Offset Nulling.*** Trimmer potentiometers *R4* and *R10* permit the user to null out the dc offsets appearing at the outputs of operational amplifiers IC4 and IC6. Begin by rotating trimmer potentiometers *R1*, *R4*, *R10* and *R13* to the centers of their adjustment ranges. Short the audio input terminals together and connect the probes of the dc voltmeter to test point U and signal ground. Adjust trimmer potentiometer *R4* so that the meter reading is between 0 and +0.02 volt. Then adjust trimmer potentiometer *R10* so that the meter reading is +0.05 volt. Remove the shorting strap from the audio input terminals and remove the voltmeter probes from the circuit.

• ***Op-Amp Gain Trim.*** A source of ac and the precision resistive voltage divider mentioned earlier and shown schematically in Fig. 8 are required for this final calibration step. The ac signal source can be a sinusoidal oscillator capable of generating a 10-volt rms output (amplitude not critical) or a small stepdown transformer with a secondary voltage rating of 10 to 25 volts rms.

If you decide to use a stepdown transformer, do not attempt to tap *T1*, the transformer employed in the project's power supply. Rather, use a separate, external transformer. If a signal generator is used, set its oscillating frequency at 1000 Hz. This is the preferred frequency at which this adjustment should be made. Of course, if a transformer is used as a source of ac, the power-line frequency (which is far lower than 1000 Hz) will be the driving frequency. Although an adjustment frequency of 1000 Hz is preferred, the transformer/power-line-frequency approach will provide good results.

Begin this calibration step by connecting the ac signal source to the input of the precision resistive voltage divider. Place MODE switch *S1* in its DOT position and DECAY RATE switch *S2* in its SLOW position. Using a convenient length of two-conductor cable, connect the audio input terminals to the precision resistive voltage divider—the grounded input terminal to the ground end of the divider and the "hot" input terminal to the 0-dB point on the voltage divider.

Rotate the shaft of 0-dB LEVEL ADJUSTMENT potentiometer *R25* so that the −3- and 0-dB LEDs (*LED28* and *LED29*) glow with equal brightness. Next, connect the "hot" audio input terminal to the −30-dB point on the voltage divider and adjust trimmer potentiometer *R1* so that the −33- and −30-dB LEDs (*LED18* and *LED19*) glow with equal brightness.

Move the hot audio input lead to the -81-dB point on the divider, and adjust trimpot R10 until the -81- and -84-dB LEDs are both illuminated. Move now to the -60-dB point and adjust trimpot R13 until both the -60-and -63-dB LEDs are lit. Having completed this, go back and repeat the previous steps for the -30, -60, and -81 dB points.

Since there is a degree of interaction between several of these trimmer-potentiometer adjustments, repeat this entire procedure until the proper results are obtained. Then proceed to the other channel's circuit and perform the third and fourth steps in the calibration sequence for that channel. (The first two calibration steps involved circuit areas that are, strictly speaking, not identified with just one of the audio channels.) When these steps (including the backtracking to compensate for interactions) have been completed, the Wide-Range Audio Meter is ready for connection to your audio system.

Applications. The Wide-Range Audio Meter can be connected to the output terminals of a stereo power amplifier, to the outputs of a preamplifier, to a tape monitor loop, to an audio mixer, or to just about any other point in an amateur or professional sound system. The addition of this project to a sound system will provide the user with useful information about the components comprising the system as well as about the program material it is called upon to reproduce.

Selecting the FAST display mode permits fast, accurate assessment of peak signal-voltage levels. This allows the user to make such adjustments as are necessary to, say, prevent his amplifier from going into clipping and possibly damaging his loudspeakers. Balancing channels for equal gain or output levels becomes a simple matter of lining up right- and left-channel glowing LEDs. Using the project as a recording-level indicator makes it possible to observe the entire range of signal levels that can, as a practical matter, be recorded—from the residual tape noise floor right up to the point at which the tape formulation saturates. In addition, the dynamic range of program material can readily be observed on the meter's LED readout, as can S/N, both directly in dB.

The "sliding" 0-dB reference-level indicator circuit will display the peak signal voltage appearing across the audio input terminals. Also, because the input signal is now referenced to the 0-dB LED, the signal-to-noise ratio can be measured. Observe the level of the audio input signal on the LED display until a momentary absence of input signal occurs. At this time, the display will quickly ramp down to the residual noise level. The absolute value of this reading is the signal-to-noise ratio.

In Conclusion. The increased use of noise-reduction systems, dynamic-range expanders, low-noise gain stages as well as high dynamic-range sources of program material such as digitally mastered and direct discs are all making contributions to enhanced playback performance levels. The Wide-Range Audio Meter that has been presented here allows these advances in the state of the audio art to be seen and measured as well as heard. ◇

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CIRCLE NO. 2 ON FREE INFORMATION CARD

BUILD AN ACTIVE POWER R BOX

BY GERALD BEENE

Converts any resistor into a 40-watt unit for load measurements.

IT IS OFTEN necessary to simulate a wide range of load conditions when building and repairing power supplies. To perform such a task, a large supply of power resistors or a power-resistor substitution box would normally be required. However, the "Active Power R Box" described here reduces the demand to a minimum. The R Box can convert any resistor, whether fixed or potentiometer, into 40-watt power resistors.

The R Box's active circuitry is programmed by an external resistor, connected across terminals A and B in the schematic diagram, so that it functions as a power resistor with a value that is 1/1000 of the external resistor's actual value. There is also a 1-ohm resistance preprogrammed into the circuit that adds to the resistance programmed in. Hence, if an 8000-ohm resistor is placed across programming terminals A and B, the resulting power resistance will be (8000/1000) + 1 = 9 ohms.

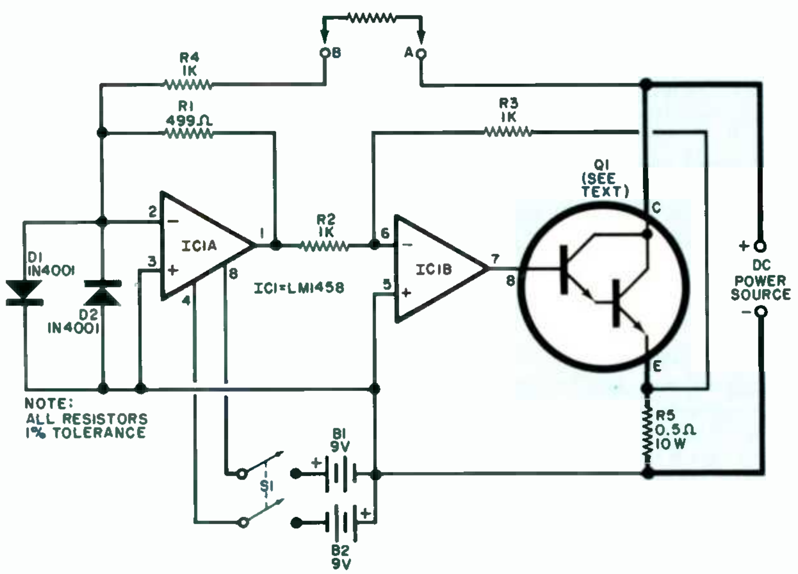
The R Box can be programmed to serve as a constant-current load if desired. This is accomplished by replacing the programming resistor with a dc bias voltage between terminal B and the negative (−) terminal. It is important that the positive side of the biasing source be connected to terminal B. The magnitude of the programming current load will be 1 ampere per volt on terminal B. For example, if terminal B is biased at 150 mV, the positive terminal of the R Box will take in 150 mA for all supply potentials.

The input potential must be restricted to 40 volts, and maximum power (input voltage times input current) must be limited to 40 watts. Also, the proper polarity must be observed or the R Box will not operate. The R Box will operate for supply outputs as low as 3 volts. The maximum allowable current is 3 amps.

When assembling the R Box, use 12-gauge wire for the high-current path (shown with heavy line in schematic diagram) and minimize the length of this wiring. Since the current drain of the dual operational-amplifier circuit (*IC1*) is only about 5 mA, a pair of 9-volt batteries for *B1* and *B2* will do fine. Mount the 10-watt, 0.5-ohm resistor (*R5*) so that the heat generated in it does not increase the heat of power-Darlington transistor *Q1*.

The heart of the R Box is transistor *Q1*. It can be a Motorola MJ1000 or any other suitable power-Darlington npn transistor. During assembly, *Q1* must be mounted on an adequate heat sink, such as the Wakefield No. NC-403-2.

The dual op amps in *IC1* sense both the input voltage and the potential across the 0.5-ohm resistor and compute the required base drive for *Q1* so that the desired performance is obtained. The accuracy of the R Box will be very good if 1% tolerance resistors are used throughout the circuit. The resistors can be rated at ¼ or ½ watt, except for *R5*, since little current flows through the circuit. ◇



The circuit of the "R Box" converts the resistance at terminals A and B to 1/1000 its value plus one ohm and circuit can handle 40 watts. Use 12-gauge wire for power circuit (heavy lines).

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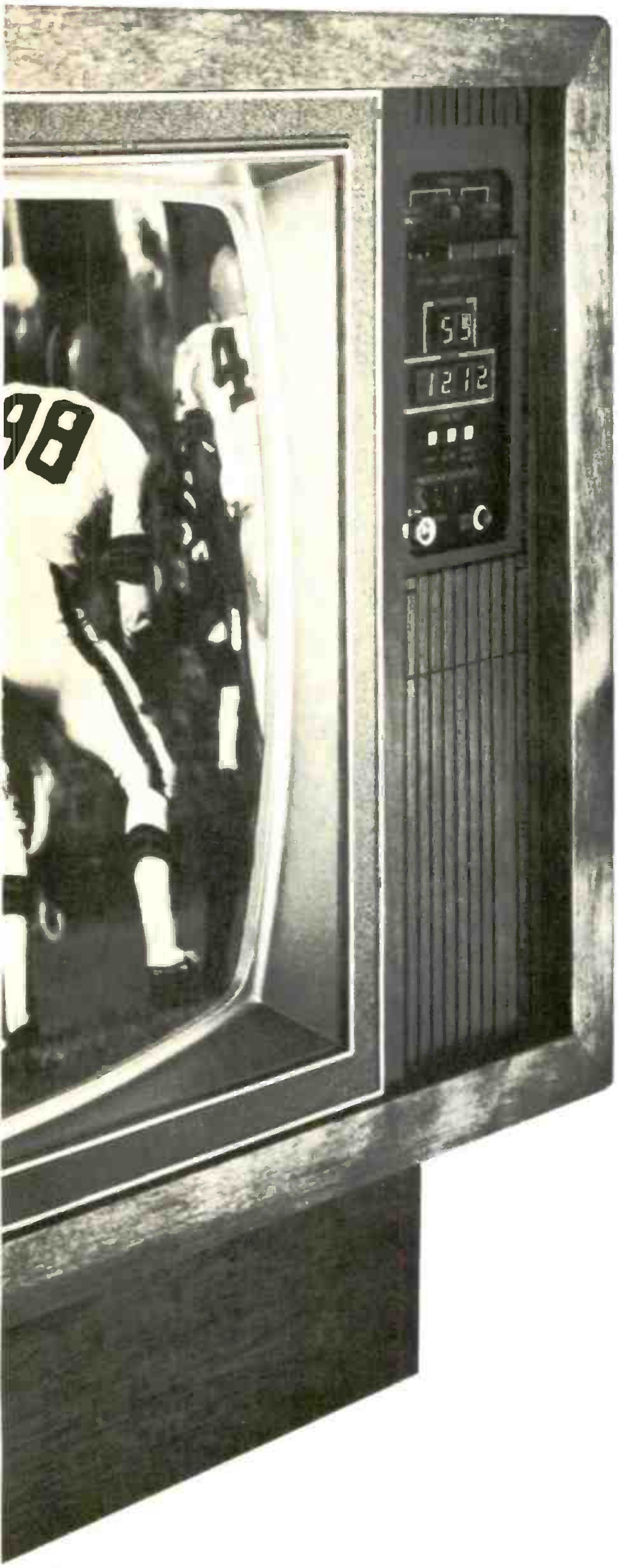

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"ZAP" NEW LIFE INTO DEAD Ni-Cd BATTERIES

That dead cell may not be completely gone. A properly applied high current can often clear a fault, making the cell useful again.

BY DOUGLAS C. MYERS

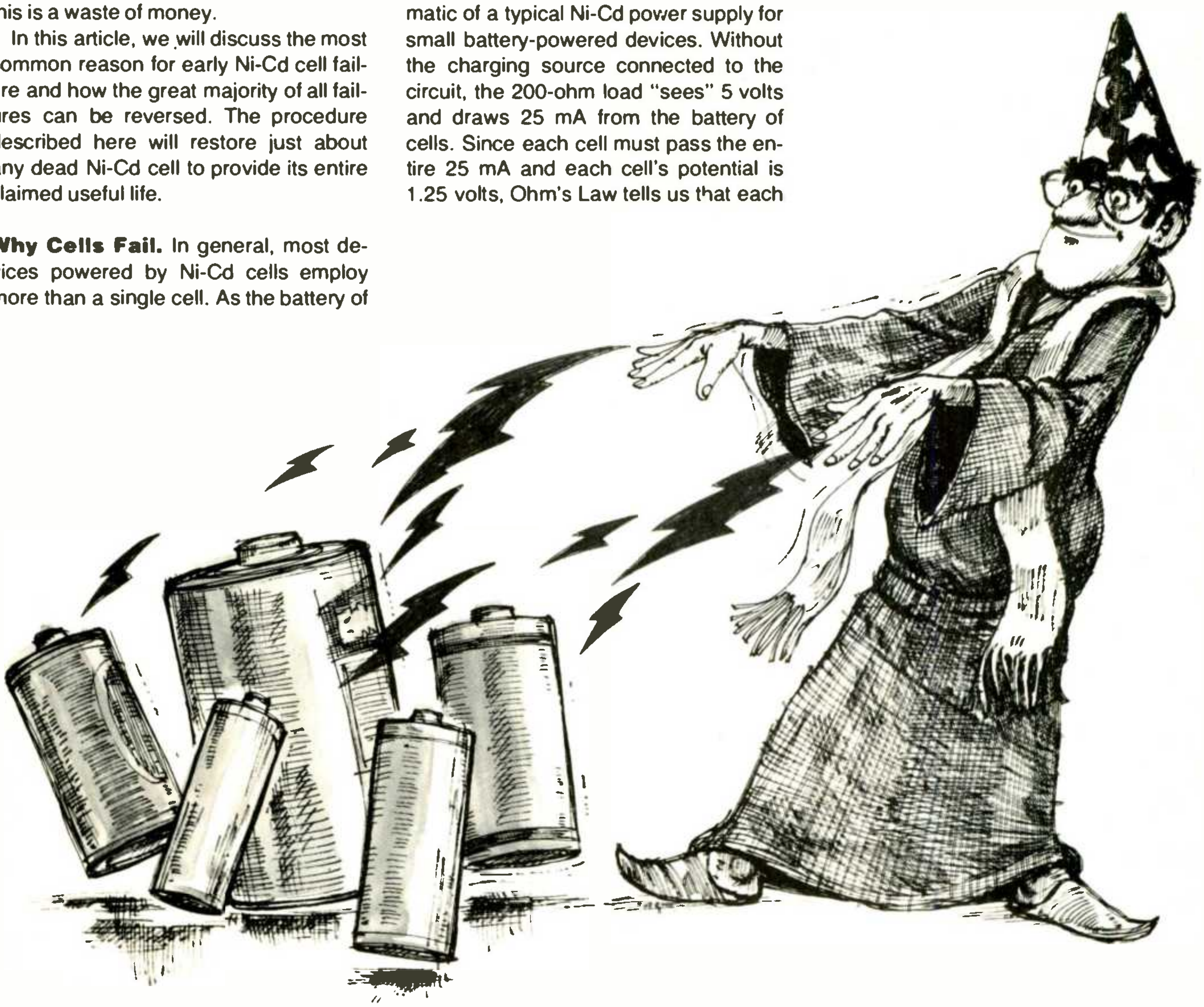
THE NICKEL-CADMIUM cell is a paradox. Capable of being charged many hundreds to many thousands of times, it occasionally fails long before its claimed life cycle comes to an end. Most people simply replace a cell that has failed with a new cell. Considering that most Ni-Cd cell failures are reversible, this is a waste of money.

In this article, we will discuss the most common reason for early Ni-Cd cell failure and how the great majority of all failures can be reversed. The procedure described here will restore just about any dead Ni-Cd cell to provide its entire claimed useful life.

Why Cells Fail. In general, most devices powered by Ni-Cd cells employ more than a single cell. As the battery of cells is discharged and recharged, the time available between recharges reduces. Almost invariably, this is due to the weakening of a single cell in the battery.

To understand the cause of such a failure—one cell "dead" while the others are still good—refer to Fig. 1, a schematic of a typical Ni-Cd power supply for small battery-powered devices. Without the charging source connected to the circuit, the 200-ohm load "sees" 5 volts and draws 25 mA from the battery of cells. Since each cell must pass the entire 25 mA and each cell's potential is 1.25 volts, Ohm's Law tells us that each cell sees the equivalent load of 50 ohms. Ideally, the four cells deliver identical performance and, hence, share the load equally.

In practice, no four cells in a battery ever exhibit exactly the same output voltage. Assume that one cell is deliver-



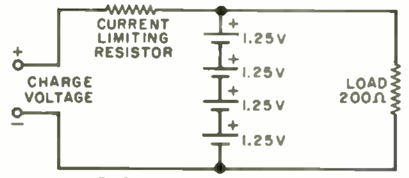


Fig. 1. Schematic of a typical NiCd supply for a small load.

ing only 1.20 volts, while the other cells are delivering their rated 1.25 volts. Now, the 200-ohm load sees 4.95 volts and draws 24.75 mA. Since all four cells must pass the entire 24.75 mA, each of the strong cells at 1.25 volts sees an equivalent load of 50.5 ohms. This means that the weak cell sees only 48.5 ohms. While this does not seem to be too unequal a distribution, note that the weak cell is working into the heaviest load and, as a result, will discharge more rapidly than the other cells in the battery. Similarly, when the cells are recharged for only a short period of time, the weak cell, which has been working the hardest, is also the one that receives the least charging power.

This unequal loading and recharging is of little consequence in normal operation. The inequality is small for any given charge or discharge cycle, due to the relatively flat output voltage Ni-Cd cells exhibit over most of their range. And a good charge tends to equalize any energy differences between cells. However, during heavy usage, one is tempted to "quick charge" the battery just enough to restore service. A combination of shallow charges and deeper-than-normal discharges tends to exaggerate the energy difference between a weak cell and the other cells in the battery system. Operated continually in this manner, the weak cell inevitably reaches its "knee," the point at which its voltage decreases sharply, long before the other cells reach the same point.

At the knee, the picture changes dramatically. Suddenly, the weakest cell sees an increasingly heavy load, which causes its voltage to drop even faster. This avalanche continues until the cell is completely discharged, even as the other cells continue to force current to flow. The inevitable result is that the weak cell begins to charge in reverse, which eventually causes an internal short.

Once an internal short develops, recharging the cell at the normal rate is futile. The short simply bypasses current around the cell's active materials. (Even though the cell is apparently dead, most of its plate material is still intact.) If the small amount of material that forms the short could be removed, the cell would be restored to virtually its original capacity once again.

Clearing the Short. Using the circuit shown in Fig. 2, the internal short can be burned away in a few seconds. In operation, energy stored in the capacitor is rapidly discharged through the dead cell to produce the high current necessary to clear the short. Current is then limited by the resistor to a safe charge rate for a small A cell.

Several applications of discharge current are usually necessary to clear a cell. During the "zapping" (restoration) process, it is a good idea to connect a voltmeter across the cell to monitor results. Momentarily close the normally open pushbutton switch several times to successively zap the cell, allowing sufficient time for the capacitor to charge up between zaps, until the voltage begins to rise. Then, with the toggle switch closed, watch as the potential across the cell climbs to 1.25 volts. If the potential stops before full voltage is reached, some residual short still remains and another series of zaps is in order. If you observe no effect whatsoever after several zaps and shorting out the cell and

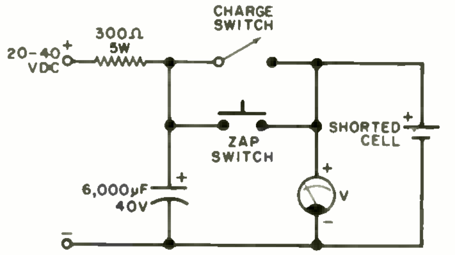


Fig. 2. Shorted cell is cleared by energy stored in capacitor.

taking an ohmmeter measurement indicates a dead short, the cell is beyond redemption and should be replaced.

Once full cell potential is achieved, remove the charging current and monitor battery voltage. If the cell retains its charge, it can be returned to charge and eventually restored to service. But if the cell slowly discharges with no appreciable load, the residual slight short should be cleared. To do this, short circuit the cell for a few minutes to discharge it, zap again, and recharge it to full capacity.

Not all Ni-Cd cells can be restored by the method described here, but most can. After restoration, a cell's life expectancy will be roughly the same as that of the other cells taken from the same service application. ◇

BUILD A FIELD DISTURBANCE SENSOR FOR SECURITY

Inexpensive alarm device detects light changes in its field of view.

BY KEN POWELL

The Field Disturbance Sensor presented here is a useful security device wherever a reasonable amount of ambient light exists, such as in an office supplies area or a store showroom. Since it does not radiate an r-f or ultrasonic signal, it cannot be easily detected. Featuring a quasi-memory, it can detect removal of an object as well as the addition of one within its field of view.

Thus, the Field Disturbance Sensor is difficult to defeat, versatile and easy to build owing to a low parts count, and readily available components can be used. Initial adjustments require only a multimeter.

Theory of Operation. The Field Disturbance Sensor functions like a simple camera, with two light-dependent resistors (LDR's) or photocells taking the place of film. A lens projects the image or field of view onto the sensitive surfaces of the photocells. The resistance of each cell is determined by the amount of light reaching it. When the field of view is normal (that is, when desired conditions in the field exist), the cell resistances will assume specific values. If an object passes through, is added to, or removed from the field, the intensity of light impinging on the cells, and thus their resistance values, deviates from the chosen norm. Any change in the ambient light level also changes the photocells' resistances.

Two IC comparators monitor the LDRs' resistances and activate an audible alarm if they vary by more than a predetermined amount. The alarm will continue to sound as long as the field is disturbed. Thus, if a person is moving through the field, the comparators activate the alarm as long as he is in view. If an object is added or removed from the field, the alarm continues to sound until the object is withdrawn or replaced, respectively.

About the Circuit. The schematic diagram of the Sensor is shown in Fig. 1. Cadmium-sulfide photocells *LDR1* and *LDR2* are connected in series to form a voltage divider and placed behind a lens (see Fig. 2). As the field of view is altered, the resistances of the photocells vary inversely in proportion to the amount of light striking their sensitive surfaces. An object entering the right side of the field of view produces a greater effect on the left photocell, and vice versa. A change in resistance of either cell causes a variation in the voltage at the junction of the two cells. This voltage is called V_{IN}.

A second voltage divider comprising *R2*, *R3*, and *R4* provides reference voltages for comparators *IC1* and *IC2*. These references are designated V_{UT} and V_{LT}. The upper threshold (V_{UT}) is applied to the noninverting input of *IC1* and the lower threshold (V_{LT}) is applied to the inverting input of *IC2*. Voltage from the junction of the photocells (V_{IN}) is applied to the inverting input of *IC1* and the noninverting input of *IC2*. Potentiometer *R1* is placed in parallel with *LDR1* so that V_{IN} can be trimmed to one

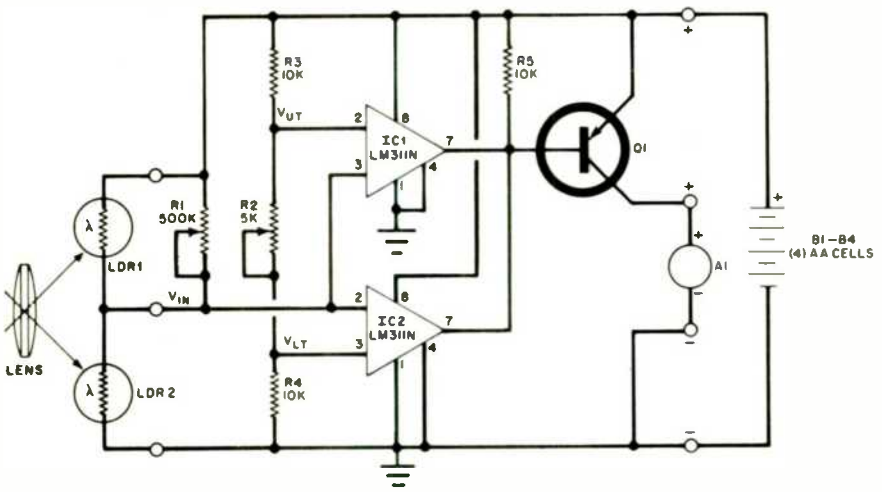


Fig. 1. Light hitting LDR's determines inputs to op amp comparators.

PARTS LIST

A1—Mallory SC628P Sonalert, or similar
B1 through B4—AA cells
IC1, IC2—LM311N comparator
LDR1, LDR2—Cadmium-sulfide photocell (Radio Shack 276-116)
Q1—Pnp silicon switching transistor (Radio Shack 276-2024)
R1—500,000-ohm trimmer potentiometer (Radio Shack 271-221)
R2—5000-ohm trimmer potentiometer (Radio Shack 271-217)
R3, R4, R5—10,000-ohm, ¼-watt, 5% tolerance resistor
Misc.—Bi-convex 50.8 × 50.8 mm lens (available for $22.60, No. 01 LDX 115, from Melles Griot, 1770 Kettering Street, Irvine, CA 92714); rubber "O" rings; cement; suitable wood, plastic or metal stock and tubing; IC socket or Molex Soldercons; battery holders (Radio Shack 270-1433); printed circuit board (available from J. Oswald, 1436 Gerhardt Ave., San Jose, CA 95125, for $4.25 ppd.); hookup wire, etc.

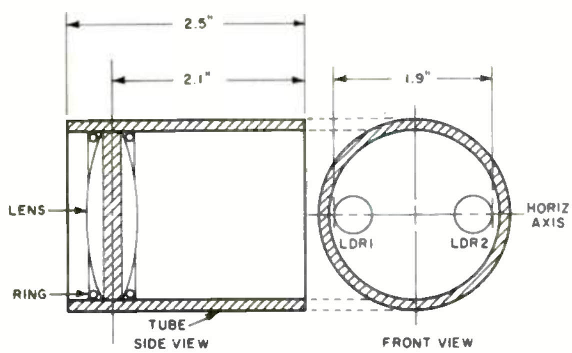


Fig. 2. Dimensions for cutting PVC pipe to make lens assembly

half the supply voltage (3 V). Potentiometer *R2* adjusts the reference voltage divider so that V_{UT} will be slightly greater than V_{IN} and V_{LT} will be slightly less than V_{IN}. When this occurs, the outputs of both comparators (uncommitted collectors on-chip) are high and *Q1* is cut off. No current flows through alarm *A1*.

Any change within the field of view will cause variations in the resistances of *LDR1* and *LDR2* and in the magnitude of V_{IN}. If the change decreases the resistance of *LDR1* or increases the resistance of *LDR2*, V_{IN} will exceed its initial value. When V_{IN} is greater than V_{UT}, *IC1* will change state and its output will go low. This will forward bias *Q1* and energize the alarm. If the photocells are affected in the opposite manner, V_{IN} will drop below its initial value. When V_{IN} is less than V_{LT}, the output of *IC2* will go low, forward biasing *Q1*, which in turn sources current for the alarm.

In effect, we have set up a voltage window by adjusting *R2*. This window is centered around V_{IN}. Any variation in V_{IN} which exceeds this voltage window activates the alarm. The window can be made very narrow—on the order of a few millivolts at the maximum sensitivity of the Sensor.

Construction. The project comprises a lens assembly, a printed circuit board, and a base. The lens is 2" in diameter and has a focal length of 2" (50.8 × 50.8 mm). A lens tube can be fabricated from a cardboard mailing tube, aluminum or PVC pipe. Two-inch I.D. PVC pipe is easily cut to size and cements readily to other plastics and wood. Dimensions for the lens tube are shown in Fig. 2. The lens is mounted in the tube with a pair of rubber "O" rings (available from hardware stores). When the rings and lens are properly positioned in the tube, the rings should be secured in place with a few drops of cement.

The base assembly can be constructed from plastic, wood or metal. Suggested dimensions are shown in Fig. 3. The prototype has a hole centered on the bottom side of the base tapped for ¼" × 20 threads. This facilitates mounting the project on a camera tripod. A small "L" bracket to hold the alarm can be formed from a 2" × 3" (5.1 × 7.6 cm) piece of steel or aluminum stock.

Photocells *LDR1* and *LDR2* are mounted on the base assembly after a preliminary test. Place the cells side by side on a flat surface about 6" (15.2 cm) from a light-colored wall which is il-

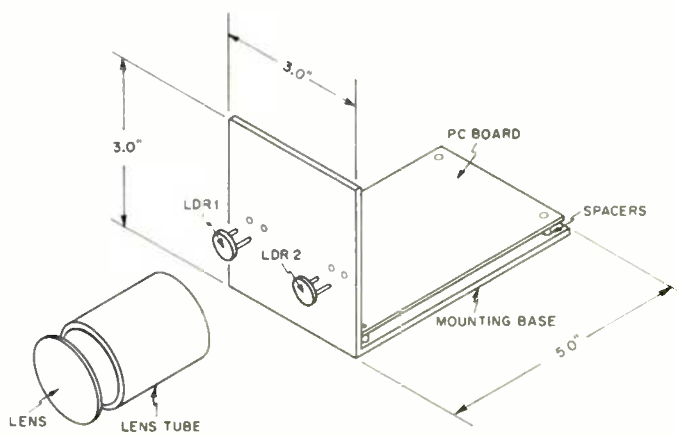


Fig. 3. Instructions and dimensions for assembling the base. A hole in the bottom can be used for tripod mounting.

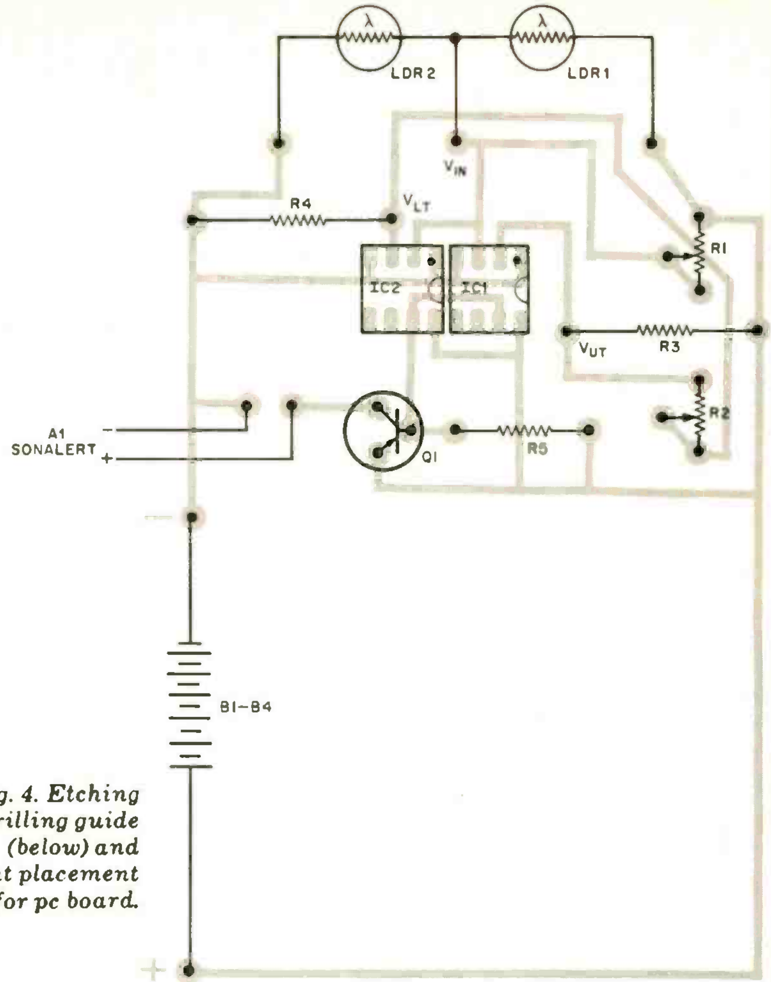
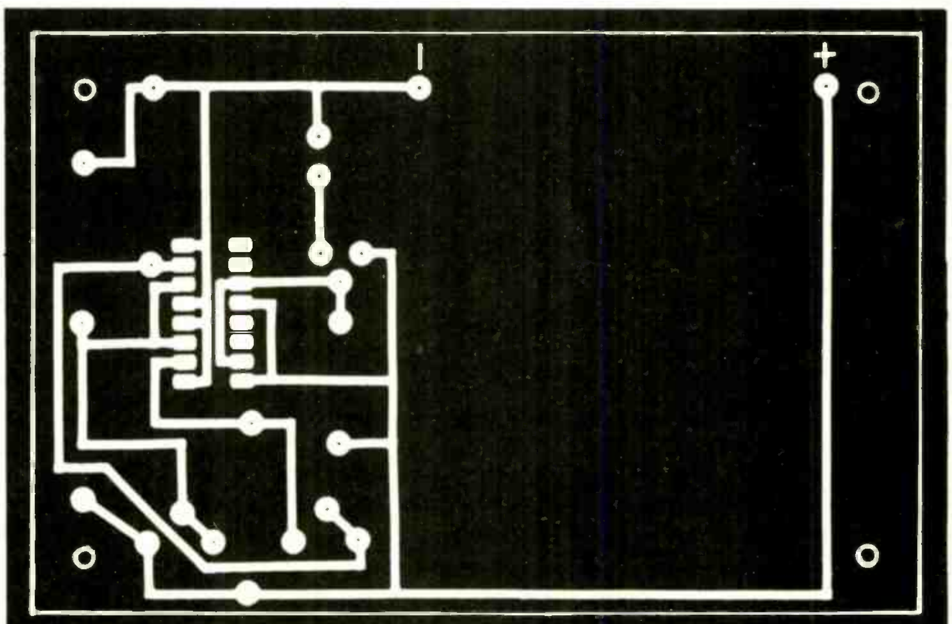


Fig. 4. Etching and drilling guide (below) and component placement for pc board.



luminated with normal ambient light. Measure the resistance of each cell and denote the one with the higher resistance *LDR1*. Then mount the LDR's on the base assembly, securing them with cement. The photocells should be spaced as far apart as possible, but be sure they can be encompassed by the lens tube. Then cement the lens tube to the base assembly.

Suitable etching and drilling and parts placement guides for the printed circuit board are shown in Fig. 4. Both IC's can be mounted in a single 16-pin socket, or Molex Soldercons can be used. Connect lengths of hookup wire to the pc pads for the LDR's and the Sonalert. Be sure to leave enough wire for the leads to reach their respective components when the printed circuit board is installed. Battery holders for the four AA cells can be mounted directly on the board. When all components and leads are in place, the pc board is mounted on the base assembly with ½" (1.27-cm) spacers and No. 4 hardware. Double check your wiring and orientation of semiconductors. Then install the batteries in their holder. The project should start beeping loudly.

Adjustment. Place the Sensor in position to cover the desired field of view. (Remember that adequate ambient light is required for correct operation of the project.) Apply the positive probe of a voltmeter to point V_{IN} and the negative lead to ground (battery negative). Adjust *R1* for a reading of approximately 3 volts. Then move the negative probe to point V_{IN} and the positive probe to V_{UT}. Adjust *R2* for the smallest voltage possible without activating the alarm. When these adjustments are performed, V_{UT} will be slightly positive with respect to V_{IN}, and V_{LT} slightly negative.

The sensor is now operational. Have some fun trying to outwit it!

Use. Keep in mind that the project operates on ambient light. Accordingly, adequate lighting must be maintained where the Sensor is to be used. Under good lighting conditions, as found in most offices and showrooms, the Sensor functions over a distance of 25 feet (8 m) or more if the intrusion or change provides a moderate contrast to the existing background. Closer in, the project will detect such changes as smoke or fire.

To alter the pattern of the field or to gain greater light-gathering power, different lenses could be used. Also, more sensitive photocells could be employed. The audible alarm could be supplemented or replaced by a relay for interconnection with an existing alarm system. There are obviously many possibilities for those inclined to experiment!

Battery life will depend on the number and duration of alarms. Quiescent current drain is only four milliamperes, so long life can be expected from the AA cells, especially if alkaline batteries are used. Of course, you could also use NiCd cells or a line-powered, regulated *low-ripple* dc supply with back-up batteries. No matter how you power the Sensor, you will find it fun to build, even more fun to attempt to defeat, and in proper applications, a very good and useful security device. ◇

NEW "NO-CAMERA" PRINTED CIRCUIT BOARD METHODS

How to use GC Calectro and Datak kits for making pc boards directly from printed matter.

BY A. A. MANGIERI

YOU CAN now copy pc etching and drilling guides directly from the printed page without using a camera or laying out an artwork master. Three pc kits that can accomplish this dream feat for the electronics hobbyist are now on the market. Two of these kits are called "Lift-It" from GC Electronics; the other is Datak's No. ER-4 kit.

The three direct-copy pc kits use different approaches to achieve essentially the same end. The Lift-It technique actually lifts the printed pattern from the page with a paint-on transparent film that has an affinity for the printing ink. The ER-4 technique used a no-camera photographic process to duplicate or reverse a printed image or a positive or negative transparency, depending on how the copy film is exposed. Either copy method will greatly speed up the artwork portion of a construction project in which a pc board is used.

Kit Lineups. The Calectro No. J4-828 Lift-It kit from GC contains seven chemicals in bottles and cans, three trays, and pc contact film. The chemical lineup includes the paint-on Lift-It film solution around which the kit is built, board-stripping solution, contact film developer, board developer, paint-on resist lacquer, aerosol resist sensitizer, and premixed ferric-cloride etching solution. Two of the trays supplied are aluminum and are meant for the developing processes, while for the developing processes, while the third tray is plastic and is for etching only. The J4-827 is essentially the same as the J4-828 except that it has Positive-type photo resist and developer.

The only additional items needed for making printed circuits boards with the Lift-It kit are a yellow "safe" light, any of several light sources for exposing the contact film and board, and copper-clad board blanks. All chemicals in the kit come premixed and ready to use.

Datak's No. ER-4 kit uses a unique direct-photocopy process, called Pos-Neg. The kit contains four chemicals, a printing frame with yellow filter, artwork aids (layout film, drafting tape, and direct-etch dry-transfer pc patterns), photocopy film, and two copper-clad pc blanks. The two types of film developer, film fixer, and ferric-chloride etchant are supplied in powder form (to be mixed when needed), while the board developer and photoresist come ready to use.

The only additional materials needed with the ER-4 kit are a photoflood lamp, three glass or plastic trays, and bottles for the home-mix chemicals.

With both kits, you receive complete details instructions on how to use them. In both cases, materials are supplied for making both cases, materials are supplied for making both positive and negative exposure masks for use with presensitized pc blanks (single-sheet original artwork can measure up to 5" by 5").

Note: The two methods are described separately on the following two pages.

THE "LIFT-IT" METHOD

If you are new to pc techniques and have little or no experience in working with photographic techniques, the GC Lift-It kit may prove to be more convenient to use. There are no photo methods used in making the first film artwork.

Since using the Lift-It method destroys the original published etching and drilling guide, it pays to photocopy both sides of the magazine page on which the artwork appears so that none of the published material is lost. Cut the page from the magazine, trim the artwork to leave about ¼" (6.35 mm) excess on all sides, and tape the artwork flat on a sheet of waxed paper. Paint the Lift-It emulsion over the entire surface of the artwork and allow to dry for 15 minutes. Repeat painting on the Lift-It emulsion and allowing it to dry until six thin, even coatings have been built up. After applying the final coating, allow the emulsion to dry for at least two hours.

When final drying is complete, soak the artwork in warm, soapy water for an hour or more. Remove the artwork from the soaking bath and carefully remove the softened paper from the Lift-It film by rubbing with the tip of your finger. Be careful to avoid tearing, stretching, or deforming the film. If particles of paper prove to be stubborn, return the artwork to the soaking bath for 15 minutes to a half hour. Finally, when all particles of paper have been removed from the film, allow the latter to completely air dry, after which you can apply a coat of the Lift-It emulsion to the ink side of the film. Make this coat as thin as possible.

You can greatly reduce the time to make the first artwork if, after applying the Lift-It emulsion, you dry it under a heat lamp or in a just-warm oven. Arrange the heating to dry the film in 3 to 5 minutes. (The wet emulsion is milky; as it dries, it becomes clear.) Using heat to speed up the drying, you can put the artwork in the soaking bath after 30 to 45 minutes of final drying. To reduce soaking time, tape the artwork, paper side up, to a clean glass plate and place both in the bath. After 10 minutes or so of soaking, cautiously rub the surface of the paper to break up any glaze. Repeatedly rub the paper gently until it begins to roll off in small bits at first and then in larger pieces. If the paper stubbornly adheres to the film, do *not* rub harder; allow additional soaking time and then proceed.

The prepared artwork can be used as is to expose presensitized pc blanks treated with positive photoresist, such as GC's No. 22-232 spray-on positive resist (use only GC No. 22-225 resist developer when using this positive photoresist—not the No. J4-630 board developer supplied in the Lift-It kit).

Positive to Negative. Assuming you are using negative photoresist and have a Lift-It positive, the next step is to make a negative of the Lift-It artwork. To do this, you use the contact film supplied in the kit. The procedure is simple. Working under safe-light conditions, you cut the film to size, place it glossy side up in a contact frame (such as GC's No. 22-280 frame), place over the film the Lift-It positive with ink side down, close the frame, and expose it under cool-white fluorescent light. If you do not have a contact frame, two clean sheets of glass will do. Excellent results are obtained with a pair of 20-watt cool-white fluorescent lamps at a distance of 4" (10.2 cm). Exposure time will first have to be established by exposing segments of a thin strip of the film for ½, 1, 2, and 4 minutes.

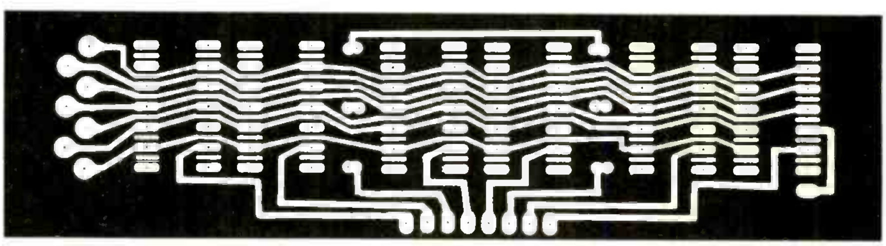
Once you have established the correct exposure time and have exposed the film through the Lift-It positive, switch to safe-light conditions, remove the film from the contact frame, and place it, dull side up, on a clean sheet of glass. Flow onto the film a liberal quanti-

THE "POS-NEG" METHOD

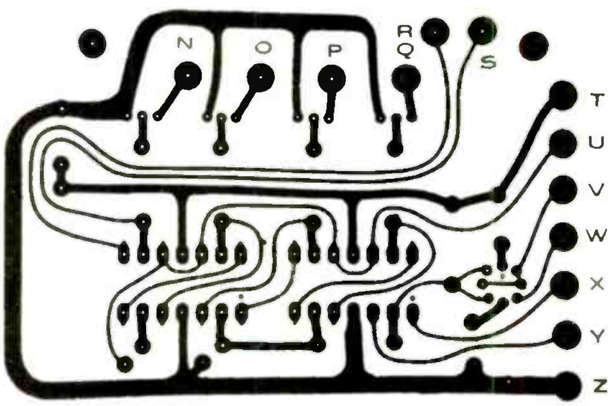
The Pos-Neg method used in the Datak ER-4 kit depends on accurate timing during the exposure of the sensitized film supplied in the kit. Using the Pos-Neg copy mode, you can directly copy the pc etching and drilling guide from the printed page. This results in a film positive that can be used directly to expose positive-resist-sensitized pc blanks.

To use the direct-copy Pos-Neg method, you begin by loading the contact frame (included in the kit) with the printed etching and drilling guide with the artwork facing up, followed by a narrow test strip of the sensitized film with its brown side up, and with the yellow filter on top. The whole is firmly sandwiched together between the contact frame and its top glass.

Next, you expose the test strip in blocks for 30 to 100 seconds at 10-second intervals. After developing and fixing the exposed film strip, you may find only one block satisfactory for your



Typical ER-4 mask.



Mask made using the "Lift-It" process.

ty of contact-film developer. Soak a wad of cotton with the developer and rub gently, in a circular motion, over the entire dull surface of the exposed film. After a minute or two, the areas of the film that were not exposed to the exposing light will begin to dissolve and come away from the film. Continue rubbing until all soft areas of emulsion have been removed. Be as gentle as possible with your rubbing because the emulsion left behind at this point will be soft. When all unwanted emulsion has been removed, rinse the film under gently running warm water and allow to dry completely.

What you should now have is a high-contrast film negative with opaque orange areas surrounding water-clear conductor areas. The details should be as sharp as they are in the Lift-It positive. Carefully examine the film negative for discontinuities and other flaws. You can repair discontinuities by cutting away the appropriate portions of the film with a razor blade or sharp X-acto knife. Pits and other flaws in the emulsion can be repaired with the paint-on resist lacquer in the kit.

Although exposure time is not critical, gross underexposure will result in complete removal of the emulsion. Conversely, gross overexposure might preclude any development at all.

needs. The "good" block will have almost opaque blacks surrounded by a slight brownish haze in the "clear" areas. It is usually necessary at this point to run off another test strip, this time in 3-second steps that span the exposure time of the "good" test block, to determine the exact required exposure time within 3 seconds.

Since the Pos-Neg technique involves both direct and indirect lighting effects, it is quite critical. An accurate enlarger timer to control the on-time of the photoflood light will prove helpful. If you do not have an enlarger timer, you can use a clock with a sweep second hand and manually control the lamp.

At all times, the presensitized film must be in intimate contact with the printed etching and drilling guide. Additionally, there can be no "print-through" in the artwork. If printing on the reverse side of the page from the etching and drilling guide is visible, back the artwork with matte black paper.

The simplest of the photo copying procedures with the ER-4 kit is the duplication of a positive from positive or negative film transparency. Here, again, you must determine the proper exposure time. You load the contact frame with the grey side of the sensitized film up, transparency, and yellow filter on top, and expose in blocks for 20 to 90 seconds in 10-second intervals. After developing and fixing the exposed film, the correct exposure time will be that represented by the block with opaque black areas surrounded by water-clear areas.

Positive to Negative. Two separate exposures of the sensitized film are required to make a positive from a film negative or vice-versa. First, you must determine a "clearing" time. To do this, you load the contact frame with the film test strip with its grey side up and place the yellow filter on top. Then, you expose the strip in blocks for 20 to 90 seconds in 10-second intervals. After this, you develop the film in fresh developer at 68° F (20° C) for 2 minutes, place it in the fixer for 5 minutes, wash it under gently running water, and allow it to dry. The test strip should go from fully opaque black to fully water clear, with one or two intermediate shades. If the first fully clear block was exposed for 60 seconds, the clearing time is 70 seconds, for example. Record the clearing time for future reference.

Now, to reverse your film transparency, you first expose the entire test strip through the yellow filter for the recorded clearing time. Then, remove the yellow filter and substitute it with the film transparency and expose again in blocks for 3 to 21 seconds at 3-second intervals. After developing, fixing, and washing the test strip, select the block that has opaque blacks with water-clear whites. You now know the exposure times for both clearing and copying.

The ER-4 Pos-Neg system sounds more complicated than it really is. Once you gain some experience with it, it will be no more difficult to use than were other "photo" methods used in the past.

FROM ARTWORK TO BOARD

With very little practice, you can easily photosensitize copper-clad pc blanks. The blanks must be flat and free of ragged edges. The best way to deal with a ragged edge is to use a fine steel file to remove copper burrs and fine emery cloth to smooth the edges. Next, thoroughly scour the copper with a steel-wool soap pad until it has a burnished finish and sheds water. Rinse thoroughly and allow to air dry, either at ambient room temperature or in a just-warm oven. Do *not* wipe the blank dry with a towel. The blank is now ready to be sensitized with photoresist.

Go to safe lighting conditions and place the pc blank with its copper side up on a couple of thicknesses of newspaper, thoroughly shake the can of spray resist, and spray a thin, even coating of the resist over the entire copper surface. Dry the resist for an hour at room temperature or for 15 minutes in a just-warm oven. Then inspect your work under safe lighting. If the coating of resist lacquer appears to be too thin, apply a second thin, even coat and again allow to dry. Before taking on a big job, develop a "feel" for the spray technique, using a piece of scrap pc blank.

Finishing Steps. Under safe light, place the sensitized pc blank in the contact printing frame and place the exposure mask on top. Make absolutely certain that the proper side of the mask is in contact with the blank. You can now expose the blank with any of four light sources, detailed in the instructions supplied with the kits. A fluorescent lamp with two 20-watt cool-white tubes at a distance of 4" from the top of the contact frame is suitable. You will have to determine the proper exposure time by trial and error with sensitized scrap pc blank.

Once the blank has been exposed, go to safe lighting and immerse it in the appropriate pc board developing solution and agitate. Remove the blank from the solution promptly when the circuit pattern appears, usually in about a minute or less. At this point, the resist is no longer sensitive to light, and you can switch back to normal lighting. Flush the developed blank under gently running water and allow to air dry at room temperature for an hour or in a just-warm oven for about 20 minutes. At no time before the board is dry should you touch the resist pattern. The pattern will still be soft and easily damaged.

After drying is complete, carefully inspect the pattern for faults and use paint-on resist lacquer or dry-transfer patterns to touch up any breaks. Then etch the blank in pc etching solution. You can speed up the etching time by preheating the etching solution by setting the bottle of solution in hot water until it becomes too hot to handle. Do *not* pour the etchant into a pot and heat it directly on a stove. Pour the etchant into a glass or plastic tray large enough to accommodate the pc blank. Place the blank, copper side down, in the hot etchant and agitate the bath by gently rocking it back and forth. Periodically check the progress of the etching after 20 minutes. When all unwanted areas of copper have been etched away, remove the pc board from the etchant and thoroughly rinse it under running water. Then remove the resist on the copper with pc board stripping solution.

The final step in making a professional-quality pc board at home is to trim the board to size and drill all component-lead and mounting holes. From initial artwork to ready-to-go etched and drilled board, the job should take between five and eight hours, depending on the size and complexity of the board. The boards you make with either of the two kits described here will be indistinguishable from boards made by a professional. ◇

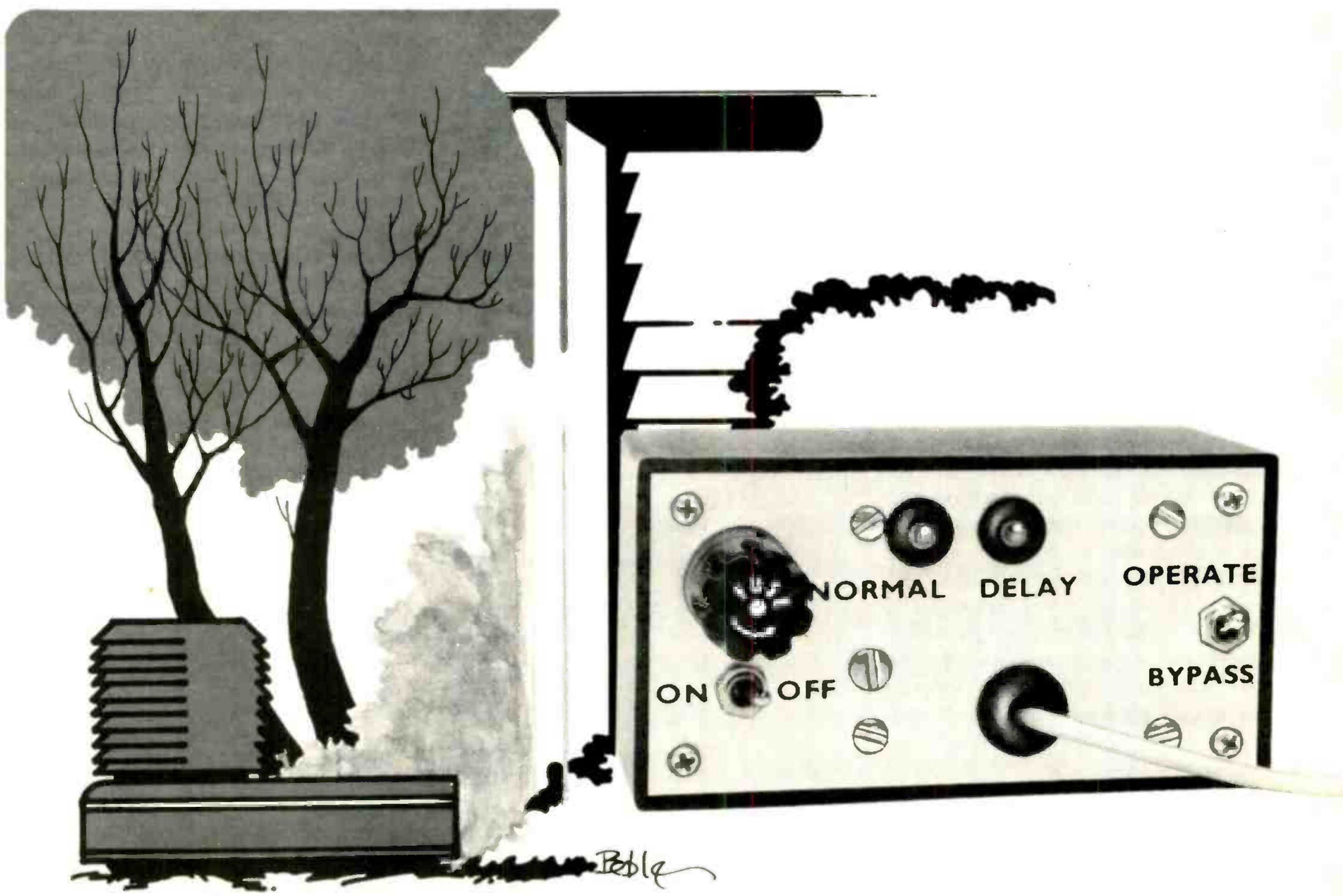
Protect Your AIR CONDITIONER WITH A "COMPRESSOR GUARD"

Add-on device prevents compressor damage due to sudden loss and reappearance of electric power and low-voltage conditions.

BY RICHARD B. FERMOYLE

POWER BLACKOUTS and brownouts, especially during hot spells when the demand for power is at its peak, can cause damage to air-conditioners, refrigerators, and freezers. You can protect your compressor-type appliances from damage due to fluctuating power with the "Compressor Guard" described in this article. It costs about $15 to build and is easily installed.

Problem Defined. If power to the compressor is suddenly lost and reapplied before system pressures can be equalized, such as during a momentary power outage, damage to the system compressor can result. A low-voltage condition, commonly called "brownout," can also cause damage. In both cases, the damage usually takes place



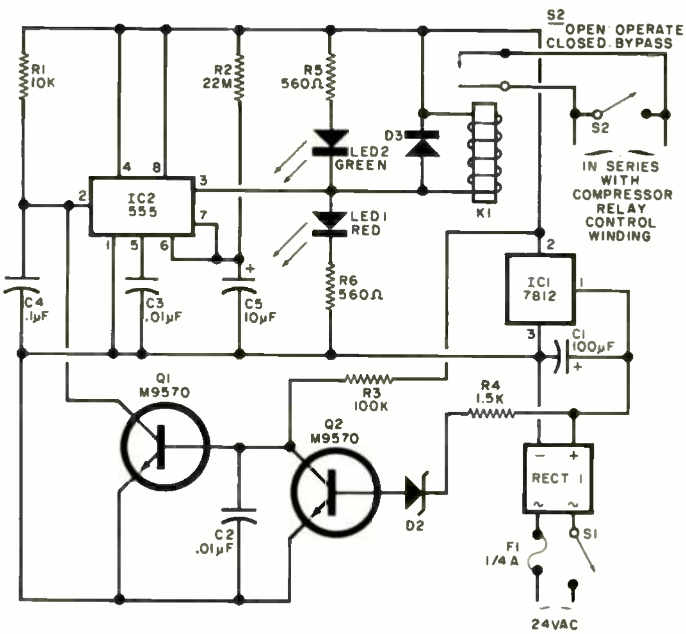


Fig. 1. Circuit provides 4.5 min. delay before power is applied.

PARTS LIST

C1—100-µF, 50-volt electrolytic
C2,C3—0.01-µF disc capacitor
C4—0.1-µF disc capacitor
C5—10-µF Tantalum capacitor (must be of a high-grade low-leakage type)
D2—Zener diode (see text)
D3—1N4001 rectifier diode
F1—¼-ampere fast-blow fuse and holder
IC1-7812 voltage regulator
IC2—555 timer
K1—Spst relay with 12-volt coil and 1-ampere contacts (Radio Shack No. 275-003 or similar) or appropriate substitute (see text)
LED1,LED2—Discrete light-emitting diode (one red, one green)
Q1,Q2—M9570 or similar npn transistor

The following resistors are ¼-watt, 10%:
R1—10,000 ohms
R2—22 megohms
R3—100,000 ohms
R4—1500 ohms
R5,R6—560 ohms
RECT1—50 PIV bridge rectifier assembly
S1,S2—Spst switch
Misc.—Socket for IC2; chassis; 4-conductor cable; rubber grommets; machine hardware; hookup wire; solder; etc.

in the compressor's drive motor as a result of overheating due to excessive current drain.

Unfortunately, the compressor and its associated drive motor are generally contained in a single sealed unit in home appliances. This means that the entire unit must be replaced as one expensive component. Although the drive motor for the compressor is usually equipped with a thermal circuit breaker, it takes time for it to sense an overload condition and disable power to the motor. The problem here is that during the time the overload condition exists, before it is sensed and power is cut off, the motor can stall and burn out. Repeated momentary power outages take their toll in weakening the motor, with the result that the motor is ultimately damaged even with the thermal circuit breaker in proper operating condition protecting the circuit.

The Compressor Guard circuit described here can be added to any compressor-type appliance to provide an added degree of protection.

How It Works. As shown in Fig. 1, the Compressor Guard is built around a 555 timer integrated circuit (*IC2*). The power source for the timer circuit is 24 volts ac, which is taken from the appliance itself. In the case of a central air-conditioning system, the 24 volts is supplied by the system's step-down transformer, as shown in Fig. 2. This transformer is part of the air-conditioning control circuitry and supplies power to the compressor's control relay through the contacts of the house thermostat. If the house is too warm, the thermostat closes and energizes the control relay, which in turn supplies power to the compressor unit. (Note: If the compressor system operates at a higher voltage, a separate 24-volt source and a relay with contacts rated for high voltage and current must be used in addition.)

The 24 volts ac is converted to regulated dc by *RECT1*, *C1*, and *IC1* in Fig. 1 to supply power for the timer circuit. Approximately 4.5 minutes after power is applied, pin 3 of *IC2* switches low and energizes relay *K1*. The period is controlled by *R2* and *C5*. With the *K1* contacts closed, a series circuit with the system's thermostat is completed. The compressor can then energize. If a momentary power outage occurs, a minimum of 4.5 minutes must lapse before power can be reapplied to the compressor. This period of time is all that is needed to allow system pressures to equalize and the compressor to be safely started once again.

The low-voltage brownout protection feature of the Compressor Guard is provided by the *Q1* and *Q2* circuits. The breakdown voltage rating of zener diode *D2* is approximately 7% to 10% less than the normal dc output potential of *RECT1*. As long as the output potential from *RECT1* is greater than the breakdown point of *D2*, *Q2* is in a state of conduction and *Q1* is held at cutoff.

If system line voltage drops, a resultant decrease in the output potential from *RECT1* will occur. If the potential drops to less than the breakdown voltage of *D2*, *Q2* goes into cutoff and *Q1* conducts. This grounds pin 2 of *IC2*, caus-

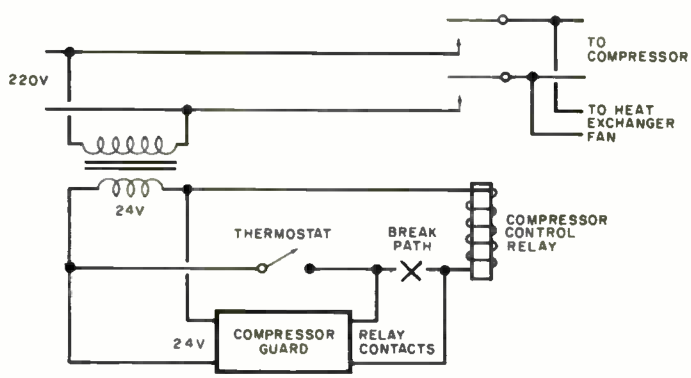


Fig. 2. Circuit showing how to wire Compressor Guard to existing system.

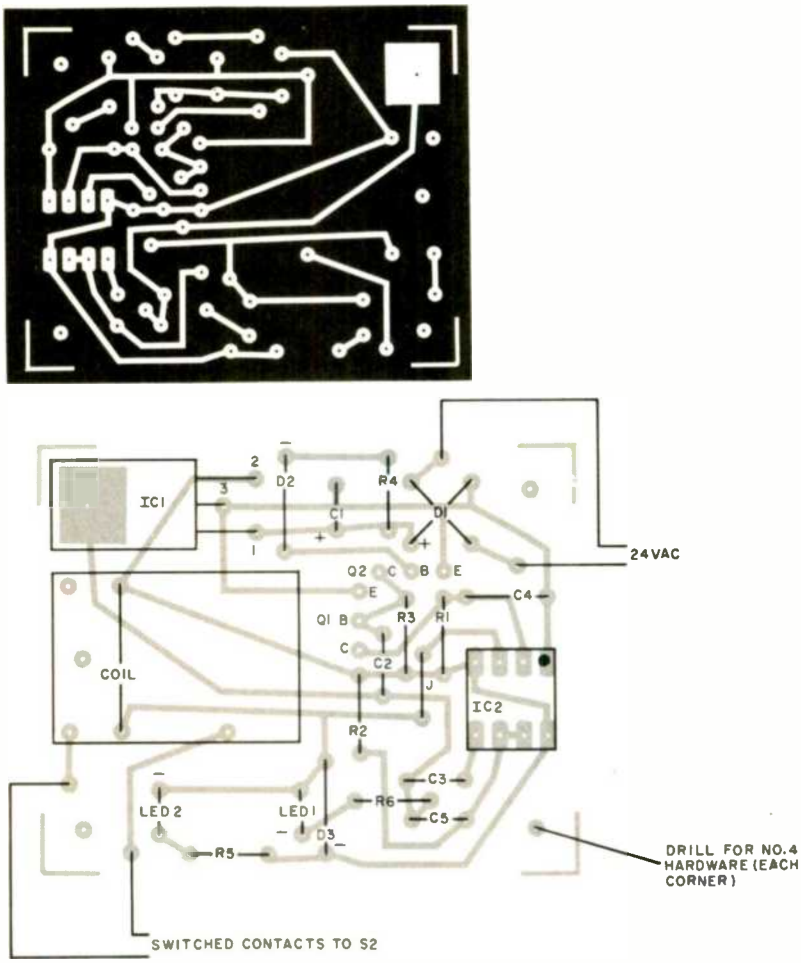


Fig. 3. It is best to assemble the circuit on a printed circuit board. An etching and drilling guide is at top with component placement guide shown below it.

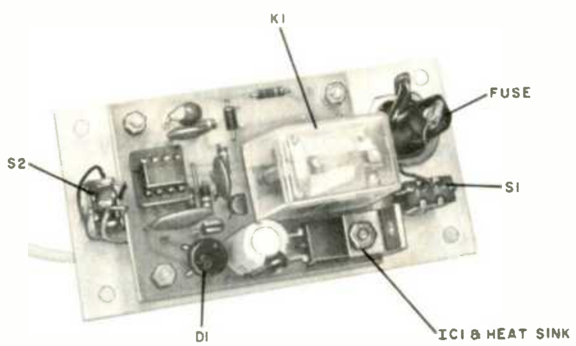


Fig. 4. Photo of prototype printed circuit board removed from enclosure.

ing pin 3 of *IC2* to switch high and deenergizing *K1*. As long as the low-voltage condition exists, *K1* remains deenergized and interrupts power to the compressor. About 4.5 minutes after the brownout condition clears, *K1* energizes to once again supply power to the compressor system.

Status indication of the timer circuit is provided by *LED1* and *LED2*, which are red and green light-emitting diodes, respectively. While the timer is cycling *LED1* is on. Then, when *K1* is energized, *LED1* extinguishes and *LED2* comes on. The LED's and resistors *R5* and *R6* are not essential to the circuit and can be omitted if desired.

The Compressor Guard can be bypassed by closing *S2*. This shorts out the contacts of *K1*. Switch *S2* is included in the circuit to allow system maintenance to be performed.

Construction. Most of the circuit is best assembled on a printed circuit board, the etching-and-drilling guide and component-placement diagram for which are shown in Fig. 3. A small right-angle bracket is used as a heatsink for regulator *IC1*.

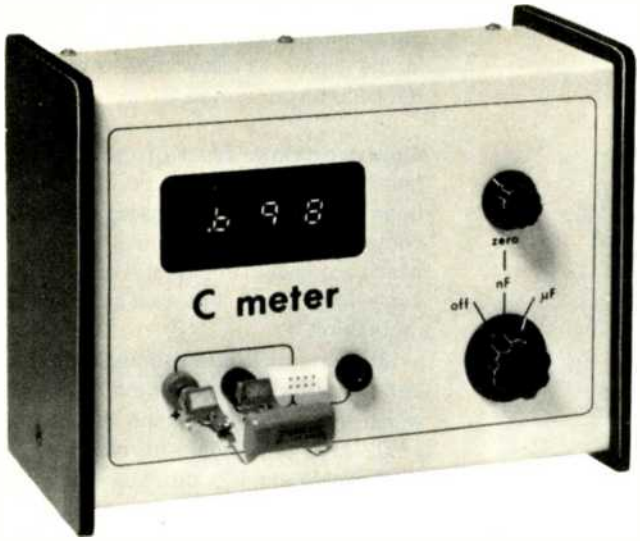
Since the pc board assembly mounts behind the front panel of the cabinet in which the circuit is housed, *LED1* and *LED2* (if used) should be mounted on the foil side of the board. Leave enough lead length on the LED's to permit the lenses to fit into small rubber grommets in the front panel when the board is mounted in place with spacers and machine hardware. The fuse holder for *F1*, POWER switch *S1*, and OPERATE/BYPASS switch *S2* should also be mounted on the front panel.

The 24-volt power and relay contact lines can be contained in a four-conductor cable that enters the cabinet through a rubber-grommet-lined hole in the front panel. The assembled printed circuit board is shown in Fig. 4.

To install the Compressor Guard in a system, use the diagram shown in Fig. 2 as a guide. Although Fig. 2 is the representation of the typical scheme used in most central air-conditioning systems, check your system closely to insure compatibility with the Compressor Guard's circuitry. Also, if you are using the Compressor Guard to protect a refrigerator or freezer that does not have the stepped-down 24 volts required, be sure to use a separate 24-volt supply and a heavy-duty relay.

With the Compressor Guard turned on and the compressor running, measure the dc output potential from *RECT1*. Then multiply the figure obtained by 0.93 or 0.90 to obtain the approximate breakdown value of the zener diode required for *D2*. If you cannot obtain a zener diode with the proper breakdown voltage, use two zener diodes that, when connected in series, yield a breakdown characteristic that is as close as possible to the required value.

One Last Note. The Compressor Guard presented here has been designed for inside installations. If you plan to use it in an outside air-conditioning installation, be sure to provide adequate weather proofing to protect the circuit from the elements. ◇



BUILD AN

Autoranging Digital Capacitance Meter

BY DAVID H. DAGE

Autoranges from 1 pF to 1 μF and from 1 μF to 4000 μF. Updates readings automatically.

THE DIGITAL-READOUT capacitance meter described here is a most useful instrument when one has to determine values of unmarked capacitors or those with unknown codes, or when checking the tolerances of marked components. Its autorange function greatly simplifies what would ordinarily be a measurement chore without this feature. Moreover, the meter's accuracy of over 1% (dependent on the tolerances of a few passive components) from 1 pF to 4000 μF enhances its utility. The project is easy on the budget, too, as low-cost 7400 series logic and 555 timer IC's are used throughout.

To operate, simply turn on the unit, connect a capacitor to the test terminals, and read the digital value displayed for any capacitor up to 1 μF. Switching a mode switch from nF to μF extends the autorange function to 4000 μF and beyond, limited only by the leakage characteristics of the test capacitor.

How it Works. Traditionally, capacitance has been measured on an ac bridge by balancing known components against the reactance of an unknown capacitance at a given, fixed frequency. However, instruments are now appearing which employ a different method to determine capacitance—they measure time. Here's how.

Mathematically, the voltage across a capacitor discharging through a resistor in a simple RC network can be expressed by the equation:

$$V_C = V_O(1 - e^{-t/RC})$$

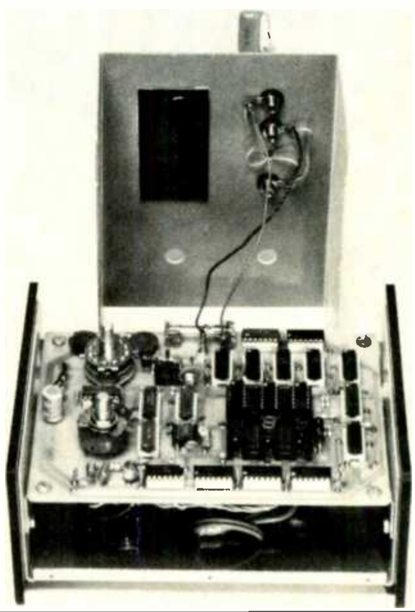
where V_O is the voltage across the capacitor when fully charged, R the resistance in ohms, C the capacitance in farads, t the time in seconds, and e the exponential constant or base for natural logarithms (approximately equal to 2.718). If we let a capacitor that has charged to a known voltage discharge through a fixed, stable resistance to some given voltage, the discharge time will be directly proportional to the component's capacitance, which then can be readily determined.

The meter described here employs this method of measurement, which readily lends itself to use with a digital readout and eliminates null adjustments. As shown in Fig. 1, the capacitance to be measured is charged through R_A and R_B. When the voltage across the capacitor equals V_{REF}, comparator A sets the flip-flop, turning on the transistor. The capacitor then discharges through R_A until the voltage across it drops to one-half V_{REF}. At this point, comparator B resets the flip-flop, which in turn cuts off the transistor. The capacitor then starts to charge up to V_{REF}, and the cycle is repeated.

A reference oscillator output at a fixed frequency is gated by the flip-flop output signal. The gated reference pulses are counted by a digital counter, decoded, and displayed directly as capacitance. The two comparators, flip-flop, transistor, reference voltage sources, and an output driver are all contained in one package—the common 555 timer IC.

The meter's autorange circuit functions during a single capacitor discharge cycle. If the three-decade counter overflows, the reference frequency input is automatically divided by ten. Simultaneously, the decimal point in the digital display is shifted one position to the right. If necessary, the process is repeated once

Interior photo of prototype.



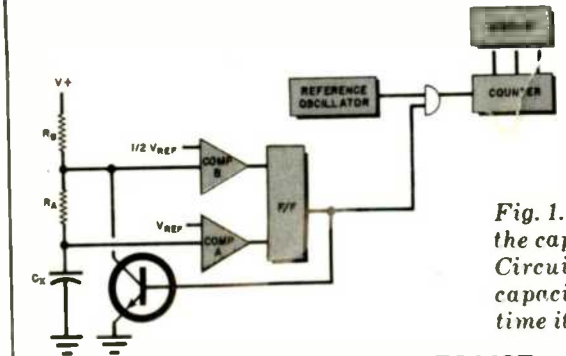


Fig. 1. Block diagram of the capacitance meter. Circuit determines unknown capacitance by measuring time it takes to discharge.

PARTS LIST

C1—4000-μF, 16-V electrolytic capacitor
C2,C4,C8 through C16, C23—0.01-μF disc ceramic capacitor
C3—0.0033-μF, 10% Mylar capacitor
C5—0.1μF disc ceramic capacitor
C6,C17—4.7-μF, 16-volt tantalum capacitor
C7—220-μF, 16-volt electrolytic capacitor
C18—0.01-μF, 5% polystyrene capacitor
C19—820-pF, 5% polystyrene capacitor
C20—470-pF, 5% polystyrene capacitor
C21—220-pF, 5% polystyrene capacitor
C22—0.005-μF, 10% Mylar capacitor
D1,D2—1N4002 silicon diode
D3 through D5—1N4154 or HEP R0600 silicon fast-recovery diode
DIS1 through DIS3—DL707 common-anode, seven-segment LED display
F1, F2—¼-ampere fast-blow fuse
IC1,IC2,IC3,IC17,IC18,IC19—7490 decade counter
IC4,IC15—7404 hex inverter
IC5—74125 Tri-State quad buffer
IC6,IC20—555 timer
IC7,IC8,IC22—7400 quad Two-input NAND-gate
IC9,IC10,IC11—7447 BCD to seven-segment decoder/driver
IC12,IC13—7474 dual D edge-triggered flip-flop
IC14,IC21—74121 monostable multivibrator
IC16—7493 4-bit binary counter
IC23—LM309K 5-volt regulator
L1—13-μH inductor
LED1, LED2—20-mA light emitting diode
R1—100,000-ohm pc mount trimmer potentiometer
R2—1-megohm, 1% tolerance, 50 ppm/°C metal film resistor
R3—100-ohm pc mount trimmer potentiometer
R4—1000-ohm, 1% tolerance, 50 ppm/°C metal film resistor
R10—25,000-ohm, panel mount linear taper potentiometer
The following are ¼-watt, 5% tolerance carbon composition resistors.
R5—1000 ohms
R6, R7—100,000 ohms
R8, R9—1500 ohms
R11,R12,R13—100 ohms
R14, R15—3300 ohms
R16 through R20—470 ohms
R2:1, R1:2, R3:3, R5:4, R4:6, R7:5, R6:7 (one set for each of three decades)—330 ohms
S1—3-pole, 3-position rotary switch
T1—16-volt center-tapped transformer
Misc.—Suitable enclosure, banana jacks or binding posts for C_X terminals, printed circuit board, fuseholders, knobs, hook-up wire, IC sockets or Molex Soldercons, hardware, solder, etc.
Note—The following items are available from Dage Scientific Instruments, Box 1054, Livermore, CA 94550: CM-6 complete kit of parts, including tested IC's, cabinet, hardware, miscellaneous items, calibration capacitor, and assembly manual, $79.95 in U.S. and Canada. CM-6B partial kit includes etched and drilled double-sided pc board, 13-μH inductor, polystyrene capacitors (C18 through C21), calibration capacitor, and assembly manual for $24 in U.S. and Canada. U.S. residents add $1 postage and handling, Canadians add $3. Californians add sales tax.

or twice, resulting in four automatically selected ranges. Additional overflow pulses are displayed by two LED's located to the left of the display.

Circuit Details. Refer to the appropriate schematic (Figs. 2 through 6) for the following detailed circuit description. Free-running 555 timer *IC20* (Fig. 2) is the basic capacitance measuring circuit, comprising the comparators, reference voltages, flip-flop, and discharge transistor described previously. The timer's discharge period is used to measure the component under test. When MODE switch *S1* is in the nF position, the discharge period is determined by *R1, R2,* and C_X. In the μF position, the interval is determined by *R3, R4,* and C_X.

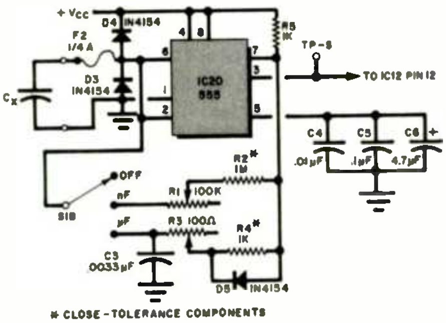


Fig. 2. Input stage has free-running 555 timer.

A second free-running 555 timer, *IC6* Fig. 3), is employed in an autocycling circuit which automatically updates the capacitance measurement. The reference frequency (about 1.4 MHz) is supplied by a Colpitts oscillator made up of IC4, L1, and *C18* through *C21*. Signals from the reference oscillator and timers *IC6* and *IC20* are combined by dual-D flip-flops *IC12* and *IC13*. One half of *IC12* synchronizes the output of *IC20* with the 1.4-MHz reference frequency, providing dual-phase (Q and $\bar{Q}$) outputs. The other half of *IC12* and *IC13* select one discharge pulse from *IC20* after the output of autocycle timer *IC6* goes high. The flip-flops disable *IC6* until the discharge pulse is completed.

The reference oscillator output is gated by *IC7* so that it passes to the counting stages during one discharge period of C_X per measuring interval. Monostable multivibrator *IC14*, when triggered by

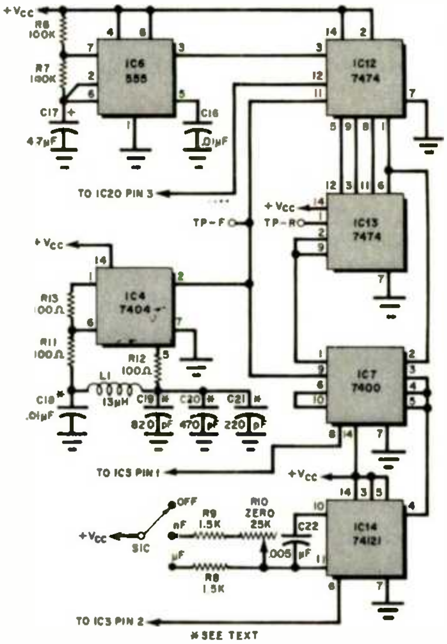


Fig. 3. Oscillator, sync., and reset circuits.

the leading edge of the synchronized discharge pulse, resets decade counters *IC16* through *IC19* and dividers *IC1* through *IC3*. When *S1* is in the nF position, the width of the reset pulse generated by *IC14* is controlled by the setting of ZERO trimmer potentiometer *R10*. This allows the user to keep stray capacitance out of the measurement.

The gated reference signal is divided by decade counters *IC1, IC2* and *IC3*. Output signals from these counters, at 1/1000th, 1/100th, and one-tenth the input frequency, are applied to Tri-State logic switch *IC5* (Fig. 5), which passes the appropriate pulse train to decade counter *IC19*. Overflow pulses from this BCD decade counter are applied to counter *IC18*, whose overflow pulses in turn are counted by *IC17*. Binary coded decimal outputs from these three decade counters are decoded by *IC9, IC10*

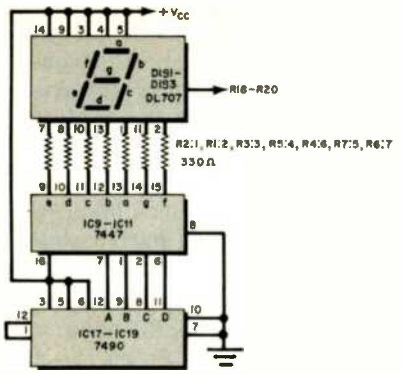


Fig. 4. Display and drivers.

and *IC11* (Fig. 4), which also drive seven-segment displays *DIS1*, *DIS2*, and *DIS3*. Current limiting for each display is performed by resistors *R2:1*, *R1:2*, *R3:3*, *R5:4*, *R4:6*, *R7:5*, and *R6:7*. (This method of identifying the resistors is discussed in the Construction section of the article.)

Now we'll examine the capacitance meter's autorange circuitry (Fig. 5). Overflow pulses from the last BCD decade counter (*IC17*) are applied to 4-bit binary counter *IC16*. This IC has four weighted binary outputs, A, B, C, and D, which are inverted by *IC15*. Lines A, Ā, B, and B̄ are decoded by the NAND gates in *IC8* to provide control signals for the Tri-State logic switches in *IC5* and selection of the proper display decimal point. Outputs C and C̄ either sink or block current from overrange indicators *LED1* and *LED2*.

Assume that counters *IC17* through *IC19* have counted 999 pulses and the display reads ".999." Upon receipt of the next pulse, the decimal point is shifted one position to the right and the display reads "0.00." Tri-State switch *IC5* then passes the ÷10 reference output of *IC3* to decade counters *IC17* through *IC19*. One-shot *IC21* and *IC22* then produce a pulse which advances the most significant counter and (leftmost) display by one so that the displays now read "1.00." If necessary, this process is repeated once or twice, resulting in an autorange function of 1000:1. After the third counting sequence, the overflow pulses cycle the two overrange LED's to indicate a count of 1000 pulses.

The 7400 series IC's require +5 volts, which is provided by the projects's power supply (Fig. 6). Transformer *T1* reduces the line voltage to a convenient value. The low-voltage ac is rectified by *D1* and *D2* into pulsating dc and smoothed by *C1*. A regulated dc output at +5 volts is provided by *IC23*. Although the regulator IC can provide a 1-ampere output, the capacitance meter circuitry requires only about 700 mA.

Construction. For the most part, the circuit is not critical and any assembly technique can be used to reproduce it. However, the measuring circuit comprising *IC20* and its associated components is critical, and should be properly shielded and decoupled from the other stages. Etching and drilling and parts placement guides for a suitable printed circuit board are shown in Figs. 7 and 8.

The pc board holds all components of the capacitance meter, less those in the power supply. It is a double-sided board on which many connections must be made between the top and bottom foil patterns. If you cannot make plated through holes, you must use wire feedthroughs to make the necessary connections. Component leads must be soldered on both sides of the board when pads are available.

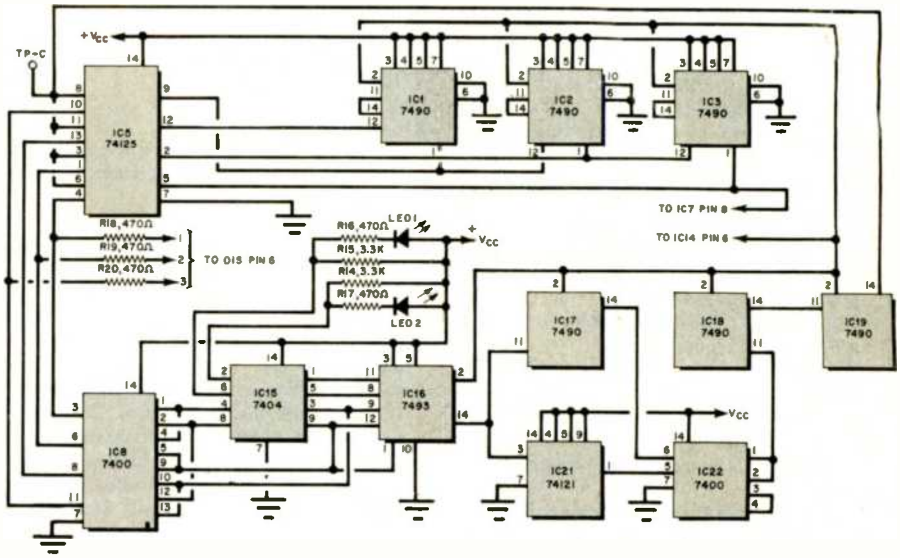


Fig. 5. Schematic of meter's autorange circuit.

Sockets or Molex Soldercons should be used to hold the integrated circuit and display packages. However, it is impossible to solder leads to pads on the component side of the board when they are under an IC socket. Because of this, all feed-through pads are accessible to the sides of the sockets. Molex Soldercons present no problem, as they can be soldered on both sides of the board. The 42 feedthrough points are identified by circles on the component placement guide (Fig. 8).

Sockets or Molex Soldercons are mandatory for the LED displays and decoder/drivers. By cutting a socket lengthwise or using Molex Soldercons on the outside pin rows, as shown in Fig. 9A, a trough is provided under the displays and decoder/drivers into which the current-limiting resistors are placed. Numbering the holes from the center both up and down will allow quick resistor placement. For example, the leads of *R2:1* occupy the second hole up and the first hole down. (See Fig. 9B.) Use small, ¼-watt resistors and, where necessary, insulate leads with sleeving.

The critical components on the board are *L1*, *C18* through *C21*, which determine the frequency of the reference oscillator, and *R1* through *R4* which with *IC20* form the basic capacitance measuring circuit.

High-quality polystyrene capacitors and metal-film fixed resistors with temperature coefficients of less than 50 ppm/°C should be used. These components, together with *IC20*, will determine the long-term accuracy of the meter and measurement error as a function of temperature. If high-quality components are used and the meter is properly calibrated, its accuracy will be at least 1% at room temperature.

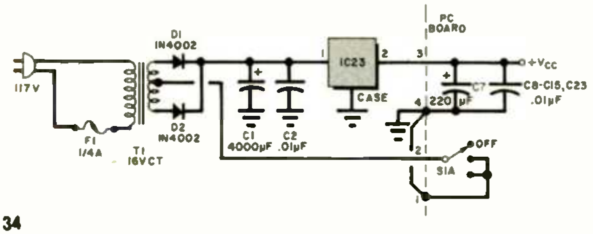


Fig. 6. Power supply circuit has a voltage regulator IC.

Checkout and Calibration. A properly functioning unit will respond as follows, and should then be calibrated. Rotate *R1*, *R3*, and *R10* fully counterclock-

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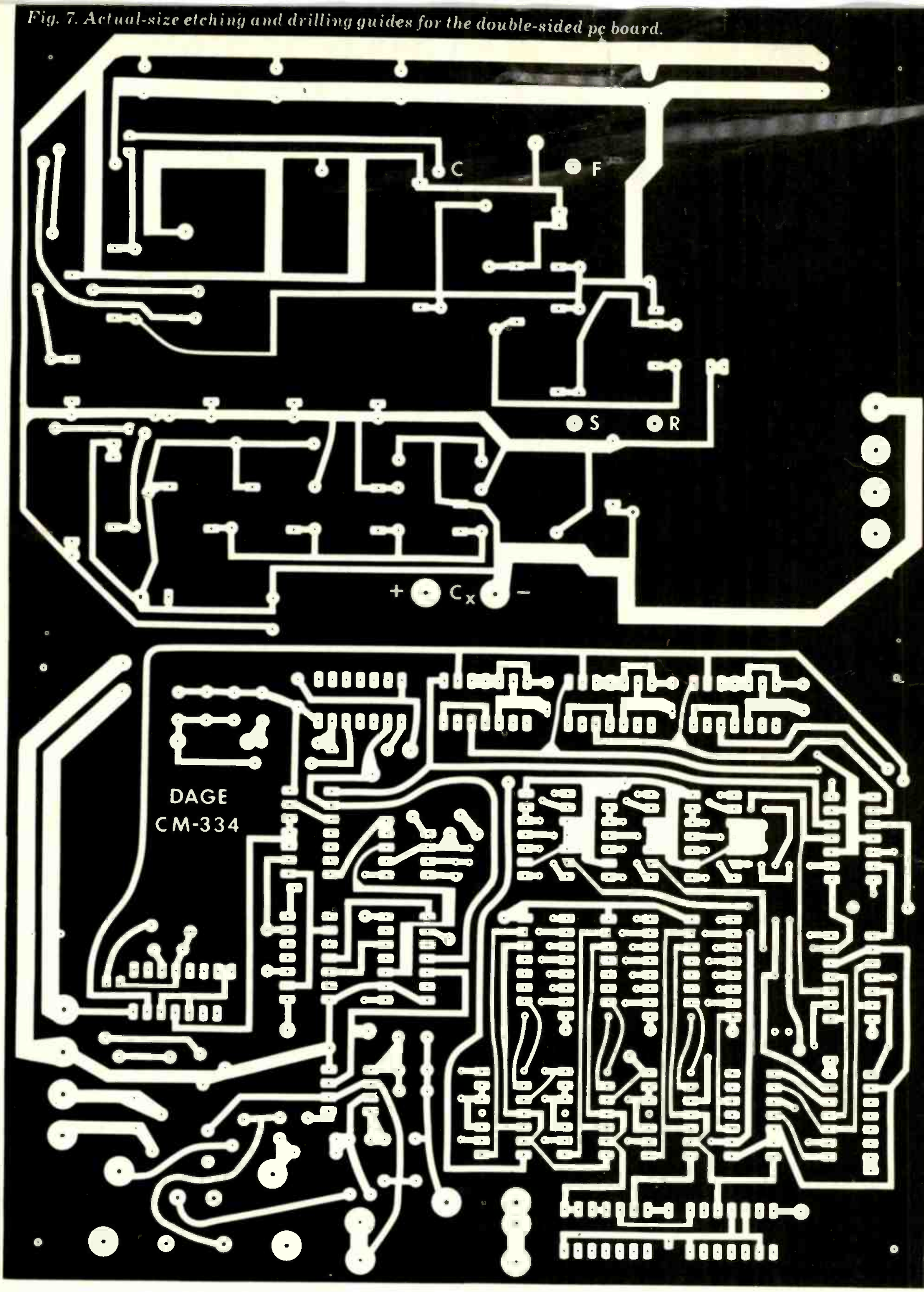
Fig. 7. Actual-size etching and drilling guides for the double-sided pc board.



wise, set *S1* to the nF position and apply power to the project. The display will light and within 2 seconds will reset to ".000." Rotate ZERO potentiometer *R10* fully clockwise. The display will indicate a few picofarads (.003 to .030 nF). Slowly rotate the ZERO potentiometer counterclockwise until the display reads ".001." Rotate the control slightly counterclockwise until it reads ".000."

Connect a reference capacitor with a known value of 0.68-μF to the C_X terminals of the meter. The display will count up for about one-half second and stop at some value which is not critical at this time. Place *S1* in the μF position. The display will read a similar value, but will not appear to flicker. Finally, place a 5000-to-8000-μF capacitor across the C_X terminals. Within a few seconds, the display will advance and the overrange LED's will cycle top on only, bottom on only, both on, both off, and repeat the sequence. The meter is now ready for calibration.

The most direct method of calibration is to measure a reference capacitor whose value is about 0.7 μF. A precision capacitor will be very expensive, so if you have access to a precision (0.1% or better) capacitance bridge, measure the value of a good-quality Mylar capacitor on it. If the capacitor is used at approximately the same temperature as the bridge environment, it will be a suitable reference component.

The 0.7-μF capacitor will be used as a reference for both the nF and μF switch positions. Setting one point for each position is all that is required, as absolute linearity is provided by the project circuitry. The reference oscillator's mean output frequency is designed to be slightly high when only *C18* and *C19* are included in the circuit. If trimmer potentiometers *R1* and *R3* cannot be adjusted to bring the display reading into agreement with the value of the reference component, install *C20* and/or *C21*. Calibration is now a matter of merely connecting the reference capacitor to the C_X terminals, placing *S1* in the μF position, and adjusting *R3* until the display matches the value of the reference component. Then, *S1* should be placed in the nF position and *R1* adjusted for the same displayed capacitance.

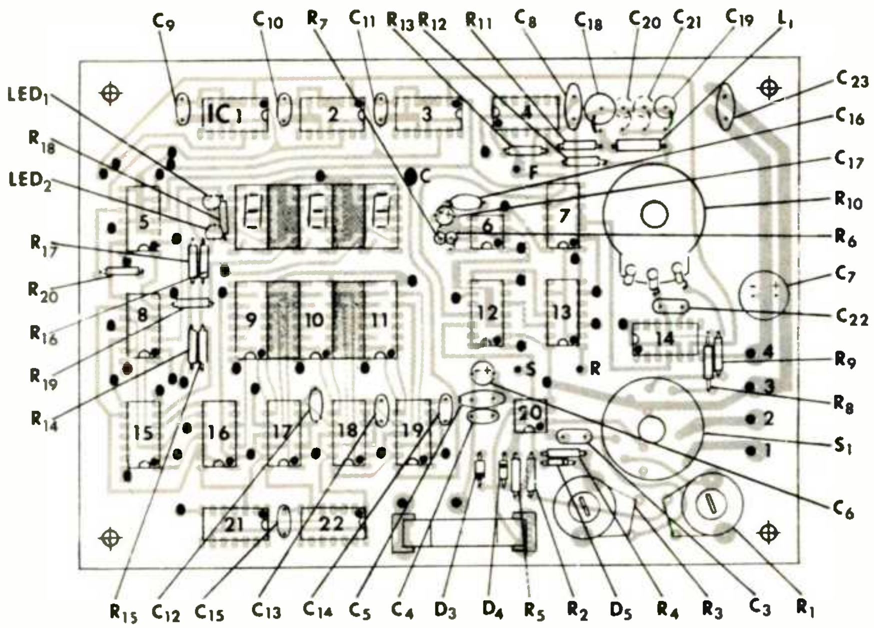


Fig. 8. Component placement guide. Numbered circles are feedthroughs.

Using the Meter. Apply power to the project by placing *S1* in the nF position. Zero the display by slowly rotating the shaft of *R10* counterclockwise until the display reads, ".001," advancing the control slightly more until a ".000" reading is obtained. Once zeroed, no further adjustments are necessary. The μF position does not require zeroing.

Connect the capacitor to be measured across the C_X terminals. Polarized capacitors must be oriented positive to positive, negative to negative. Do *not* connect charged capacitors to the project. Although the input circuitry is protected with clamping diodes and a fuse, charged capacitors might damage the project.

Capacitance is displayed in either nF or μF, depending on the setting of *S1*. Values greater than 1000 nF should be read in the μF position. Capacitance greater than 1000 μF is determined by observing the overrange LED's to the left of the display. Because these two LED's cycle every ⅔ second, they are easily observed. If the top LED glows, 1000 μF is indicated; if the bottom LED glows, 2000 μF; if both, 3000 μF.

This sequence will then repeat, with two dark LED's representing 4000 μF; the top LED glowing, 5000 μF; the bottom LED, 6000 μF; both on, 7000 μF; both dark, 8000 μF; and so on until the cycling stops. Values up to several thousand microfarads can be measured. The upper limit is determined mainly by capacitor leakage, and to a lesser extent by your patience! Capacitors with high leakage will never charge to V_{REF}, and thus will not trigger the discharge cycle.

When using the capacitance meter with *S1* in the nF position, treat the reading as if it were in picofarads if the decimal point is to the left. That is, ".084" should be read as 84 pF, and ".003" as 3 pF. With a little experience, you will quickly become familiar with the autorange function and the behavior of the overrange LED's. ◇

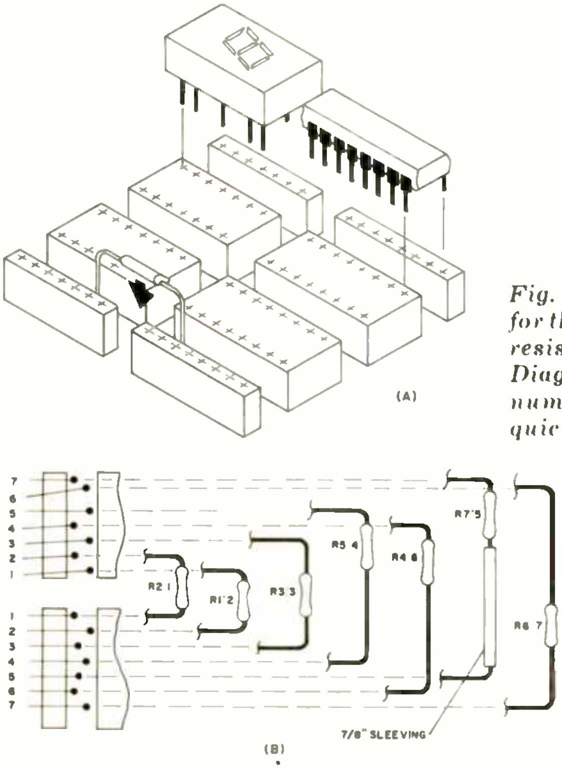


Fig. 9. A trough is provided for the current-limiting resistors as shown in (A). Diagram at (B) shows how numbering the holes allows quick resistor placement.

BUILD A LOW-COST A/D CONVERTER

Two-chip, four-channel converter works with any 8-bit computer.

BY W. L. GREEN

INTERFACING a digital computer with the "real" world requires some means of converting analog (slowly varying) signals into a digital form that can be used by a computer. The low-cost ($30) analog-to-digital (A/D) converter described here can accept up to four channels of analog data, spanning from 0 to +2 volts dc, and change this information into 3½ digits of BCD data.

With such a converter, a computer need not be limited to keyboard entry for many game programs. Now, joysticks or potentiometers can be used. And such real-world sensing of variables like voltage, current, temperature, frequency, and various levels of acidity, salinity, and chemical concentrations can make your computer a powerful and versatile controller. As a bonus, the A/D converter becomes a powerful test instrument for circuit design and troubleshooting. In this application, up to four channels of voltage, current, and resistance can be monitored with proper input adapters.

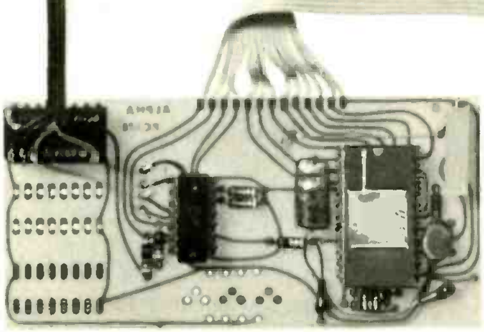
Technical Details. The converter produces five conversions per second. It has four input channels and 3½ digits of BCD data output. It is also TTL compatible in input and output and will work with any 8-bit computer that has a latched output port and a three-state input port. Digit and channel selection is under software control. Since the circuit is all CMOS, very little power is required.

As shown in Fig. 1, the A/D converter employs two IC's and a handful of passive components. One of the four input switch *IC2* to form the input for A/D converter *IC1*. The analog switches are set by data written out by the latched output port of the computer. Resistors *R6* through *R9* provide pullup for the analog switch select lines.

A/D converter *IC1* is a pulse-modulation type. Its chip contains the conversion circuitry, an addressable digit latch, multiplexer, BCD encoder, and system clock.

Conversion control, output digit select, and the output latch are connected to the computer's output port. Data written to this port control the data placed on the four output lines of *IC1*. The four data output lines from *IC1* are connected to the computer's three-state input port's lower four bits (Dϕ through D3). The upper four bits (D4 through D7) are grounded.

Trimmer potentiometer *R1* determines the reference voltage used by



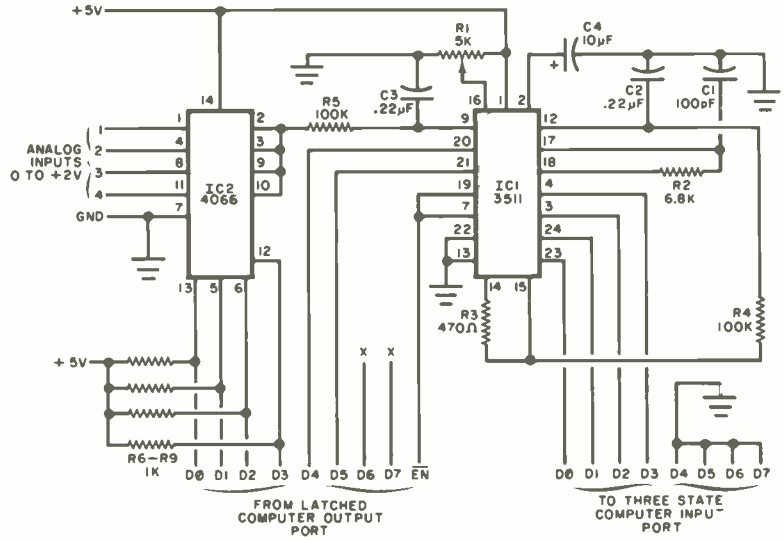
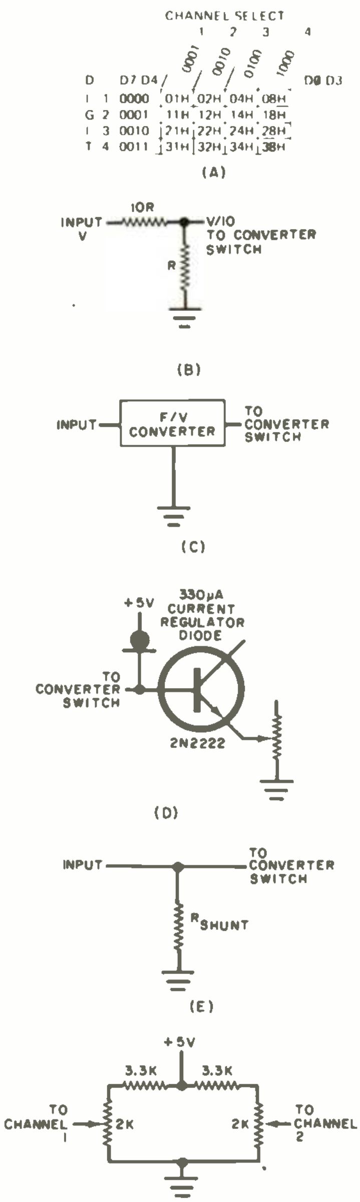


Fig. 1. Analog switch IC2 selects the input drive for A/D converter IC1. Up to four inputs can be used.

PARTS LIST

C1—100-pF disc
C2, C3—0.22-µF, 10-volt Mylar
C4—10µF, 10-volt electrolytic
IC1-ADC—3511 A/D converter (National Semiconductor)
IC2—4066 quad analog switch
R1—5000-ohm, 10-turn trimmer pot.
R2—6800-ohm, ¼-watt resistor
R3—470-ohm, ¼-watt resistor
R4, R5—100,000 ohm, ¼-watt resistor
R6 through R9—1000-ohm, ¼-watt resistor
Misc.—Printed circuit board; edge connector; multilead ribbon connector; IC sockets (optional); hookup wire; solder; etc.



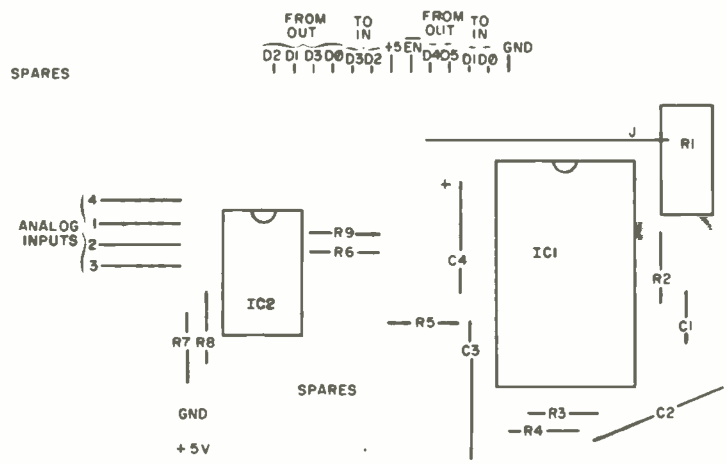


Fig. 3. Actual-size foil pattern (below) and component layout (above).

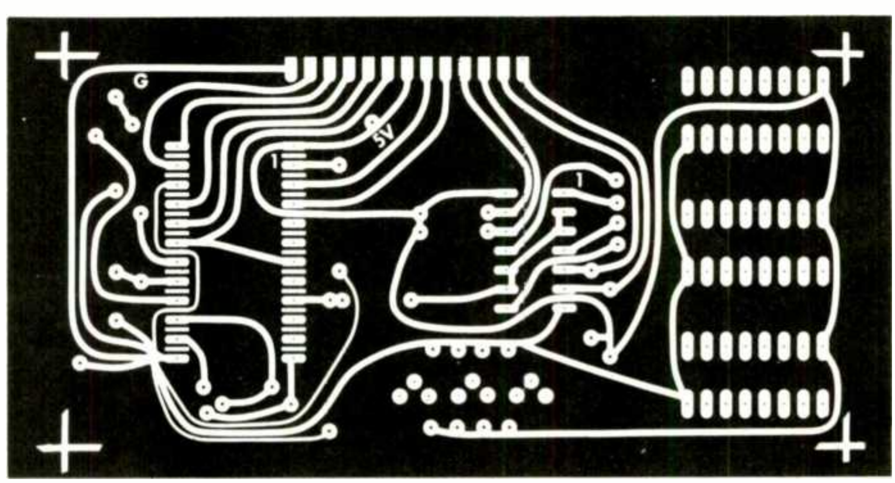


Fig. 2. Channel-digit select is shown at (A); a 10:1 voltage divider is at (B); a frequency-to-voltage scheme at (C); temperature converter (D); current measurement (E); and joystick input (F).

TABLE I—8080 ASSEMBLY LISTING

Assembly listing for 8080 (IMSAI). Inputs three most significant digits and writes to front panel.

4000	3E 11	BGN	MVI	A, 11H	Load A with Dig2, Ch1
4002	CD 38 40		CALL	INPUT	
4005	32 35 40		STA	DIG2	
4008	3E 21		MVI	A, 21H	Dig3, Ch1
400A	CD 38 40		CALL	INPUT	
400D	32 36 40		STA	DIG3	
4010	3E 31		MVI	A, 31H	Dig4, Ch1
4012	CD 38 40		CALL	INPUT	
4015	32 37 40		STA	DIG4	
4018	3E 00		MVI	A, 00H	
401A	2A 35 40		LHLD	DIG2	Dig2 L, Dig3 H
401D	BC		CMP	H	Compare H for 0
401E	06 00		MVI	B, 00H	Clear B
4020	C4 4A 40		CNZ	SUB	Gosub if H≠0
4023	3A 37 40		LDA	DIG4	
4026	FE 00		CPI	00H	
4028	CA 2D 40		JZ	WRT	If A≠0, fall thru
402B	3E 64		MVI	A, 64H	
402D	80	WRT	ADD	B	A=A+B
402E	2F		CMA		Invert data
402F	D3 FF		OUT	0FFH	Write it
4031	C3 00 40		JMP	BGN	Do again
4034		STR	DS	01	
4035		DIG2	DS	01	
4036		DIG3	DS	01	
4037		DIG4	DS	01	
4038	D310	INPUT	OUT	10H	Setup port 10H
403A	CD 40 40		CALL	DLY	A/D settling time
403D	DB 10		IN	10H	Input A/D data
403F	C9		RET		
4040	11 00 30	DLY	LXI	D, 3000H	200-ms delay
4043	1B	UP	DCX	D	
4044	7A		MOV	A, D	
4045	B3		ORA	E	
4046	C2 43 40		JNZ	UP	If D>0 do again
4049	C9		RET		
404A	C6 0A	SUB	ADI	0AH	A+A+0AH
404C	25		DCR	H	H=H−1
404D	C2 4A 40		JNZ	SUB	If H>0, do again
4050	85		ADD	L	A=A+L
5051	47		MOV	B, A	B=A
4052	C9		RET		
4053	76		HLT		

TABLE II—6800 OP CODE LISTING

Op code listing for 6800. Inputs four digits from channel 1 and stores data in memory in BCD format.

01	BDN	LDAA	01H	Load digit 1, channel 1 into A
02		BSR	INPUT	
03		STAA	DIG1	Store A in memory
04		LDAA	11H	
05		BSR	INPUT	
06		STAA	DIG2	
07		LDAA	21H	
08		BSR	INPUT	
09		STAA	DIG3	
10		LDAA	31H	
11		BSR	INPUT	
12		STAA	DIG4	
13		JMP	BGN	Do again
14	DIG1	RES	01	Res —reserves one byte of memory
15	DIG2	RES	01	
16	DIG3	RES	01	
17	DIG4	RES	01	
18	INPUT	STAA	insert	output port =
19		BSR	DLY	200-ms delay for A D settling
20		LDAA	insert	input port =
21		RTS		
22	DLY	LDAA	--	enter values here and 23 to create
23	UP	LDAB	--	a 200—ms delay
24	UP1	SUBB	01	
25		BGT	UP1	do until B-0
26		SUBA	01	
27		BGT	UP	do until A=0
28		RTS		

TABLE III—ASSEMBLY LISTING FOR 2650

Assembly listing for 2650 (Central Data). Inputs three most significant digits and writes to data bus on WRTD instruction. Converts to hex before outputting data.

1600	75 FF		CPSL	FF	Clear PSL and setup register bank 0
1602	05 11	BGN	LODI, 1	11	Setup for channel 1, digit 2
1604	3B 20		BSTR, 3	INPUT	
1606	CA 1B		STRR, 2	DIG2	
1608	05 21		LODI, 1	21	
160A	3B 1A		BSTR, 3	INPUT	
160C	CA 16		STRR, 2	DIG3	
160E	05 31		LODI, 1	31	
1610	3B 14		BSTR, 3	INPUT	
1612	CA 11		STRR, 2	DIG4	
1614	08 0D		LODR, 0	DIG2	
1616	0B 0C		LODR, 3	DIG3	
1618	B8 24		BSFR, 0	SUB	BR if DIG3≠0
161A	0B 09		LODR, 3	DIG4	
161C	18 02		BCTR, 0	WRT	BR if DIG4-0
161E	84 64		ADDI, 0	64	
1620	F0	WRT	WRTD, 0		Write it
1621	1B 5F		BCTR, 3	BGN	do again
1623	00	DIG2	RES	01	RES 01 reserve one byte
1624	00	DIG3	RES	01	
1625	00	DIG4	RES	01	
1626	D5 00	INPUT	WRTE, 1	00	Setup port 00
1628	3B 03		BSTR, 3	DLY	A/D settling time delay
162A	56 00		REDE, 2	00	read port 00 into R2
162C	17		RETC, 3		
162D	77 10	DLY	PPSL	10	select register bank 01
162F	05 FF		LODI, 1	FF	gives 200 ms delay with 1633
1631	A5 01	UP	SUBI, 1	01	
1633	06 40		LODI, 2	40	
1635	A6 01	UPI	SUBI, 2	01	
1637	5A 7C		BRNR, 2	UP1	do again until R2 0
1639	59 76		BRNR, 1	UP	do until R1 0
163B	75 10		CPSL	10	select register bank 00
163D	17		RETC, 3		
163E	A7 01	SUB	SUBI, 3	01	R3 R3-1, converts BCD to hex
1640	84 0A		ADDI, 0	0A	R0=R0+0A
1642	5B 7A		BRNR, 3	SUB	do until R3 0
1644	17		RETC, 3		
1645	40		HALT		

IC1. The other passive components determine clock frequency, provide signal filtering, and interconnect *IC1*.

Software. The digit and channel select codes are shown in Fig. 2A. The values shown are in hexadecimal code. To use the table, move down the rows until the proper digit is located. Then move over until the proper channel is located. The hex number at this point is the data to be written to the output port to set up the converter. The strobe that enables the output port (EN) must be active low when connected to the converter. If necessary, an inverter can be wired into the circuit to perform the inversion.

When reading data from the converter, it is necessary to access only the correct input port. Examples of programs written for an 8080, 6800, and 2650 are shown in Tables I through III. The program flow is essentially the same for any 8-bit computer. The digit/channel information is loaded into a register and then the program is stepped to a subroutine (INPUT) and outputs that register to the output port. A 200-ms delay (DLY) subroutine is used to allow the A/D converter to settle. Then the data is read from the input port into a register.

Upon returning from the INPUT subroutine, the BCD digit is stored in memory (DIGX) and is repeated for each digit required before branching back to the

TABLE IV—BASIC SAM GAME

```
SAM (surface-to-air missile) GAME
Central Data Basic (2650)

0000    RESTORE
0010    READ, R, W, M, P, Z
0020    DATA 0, -1, 0, 11, 0   REM sets up port 0, chan#1, digit#3
0100    EXTOUT 0, 33
0105    X=SIN(1)   REM delay for A/D settling
0110    EXTIN 0, B   REM reads port 0, chan=1, digit=3 into B
0120    EXTOUT 0, 49
0125    EXTIN 0, A
0130    EXTOUT 0, 34
0135    X=SIN(1)
0140    EXTIN 0, D
0150    EXTOUT 0, 50
0155    EXTIN 0, C
0160    A=INT (A*10+B)*.8)+1
0165    C=(C*10+D)*4
0170    ERASE   REM clears screen
0175    IF R>17 GOTO 1010
0200    W=W+1
0210    P=P-1
0220    IF W>10 W=10
0230    IF P<0 P=0
0240    PRINT@14, 15' MISSILES FIRED'#W
0250    PRINT@15, 15' MISSILES LEFT'#P
0300    PRINT@13, 9'I'
0310    PRINT@14, 8'I'
0320    PRINT@15, 5'IIIII'
0330    PRINT@10, 50'I I I'
0340    PRINT@11, 50'IIIIIII'
0400    Z=Z+4
0410    Y=1+INT(RND(7))
0500    PRINT@Y, Z'++++++'
0510    PRINT@Y-1, Z'     +'
0520    PRINT@Y+1, Z'     +'
0530    IF Z>50 GOTO 0900
0600    READ Q, V, L
0610    DATA 12, 9, 1
0620    RESTORE 0610
0630    IF W-0 GOTO 0800
0640    PRINT@Q, V'↑'
0650    IF C+1>19 L=3
0660    IF C+1>31 L=6
0670    IF V>C+1 V=V-1
0680    IF V<C+1 V=V+L
0700    Q=Q-1
0710    IF Q=A IF V=C+1 GOTO 0740
0720    IF Q<A GOTO 0740
0730    GOTO 0640
0740    PRINT@A, C+1'X'
0800    PRINT@14, 40'TARGET RANGE'#Y' BEARING'#Z
0810    PRINT@15, 40'MISSILE RANGE'#A' BEARING'#C+1
0820    IF C>Z IF C<Z+6 GOTO 0880
0825    IF P=0 M=1
0830    IF M=1 GOTO 0170
0835    IF R>0 GOTO 0850
0840    INPUT'    FIRE'R
0845    IF R=22 GOTO 0100
0850    R=R-1
0860    IF R<0 GOTO 0800
0870    GOTO 0100
0880    PRINT@A.C+1'X DESTROYED'
0890    PRINT@15, 5
0895    GOTO 1000
0900    PRINT@11, 50'DESTROYED'
0910    PRINT@15, 5
1000    STOP
1010    PRINT@A, C+1'X'
1020    PRINT@15, 40'MISSILE    RANGE'#A'  BEARING'#C+1
1030    R=R-1
1040    IF R>17 GOTO 0100
1050    R=0
1060    GOTO 0840
1070    END
```

This program prints a missile launching site, a factory, an airplane (bomber), and a printout of the airplane's and missile's range and bearing. When FIRE appears at the bottom of the screen, type a number (1 through 10) for the number of missiles you wish to fire. The missiles will fire in sequence. Type 22 to clear the screen and display the missile range and bearing adjustments. You may then adjust the controls to alter these values. After 5 shots, the program will return to FIRE. If you input 1 (CRLF), then carriage-return/line-feed, an arrow will print the track of the missile until it reaches its range, and an X will appear to simulate an explosion. The object is to hit the plane on its fuselage, in which case, X DESTROYED will be printed. You have 10 missiles. If you do not destroy the plane in 10 shots, or if the plane reaches space 50 on the screen before you destroy it, the plane will destroy the factory. The aircraft will progress across the screen at the rate of 4 spaces for each missile fired. However, the plane will move up and down by a random amount (line 0410 controls this).

Note that the FIRE 22 routine does not subtract from the missiles remaining, but you cannot destroy the plane in this routine either. All entries must be followed by CRLF. After each missile is fired, and FIRE is displayed, you can adjust the range and bearing controls to alter the missiles course and range.

beginning (BGN). The 8080 listing also includes a routine to convert the three most significant digits into hex code and place the result in storage (STR). When programming, allow for the fact that this data has no decimal point.

Some typical input adapters are shown in Fig. 2B through 2F; B, C, and E are conventional, while D illustrates a temperature converter. If you use this or a similar circuit, allow for any voltage offset in this type of converter. Also, keep in mind that only the two least significant digits are required for a temperature reading. This data should be viewed as relative and not absolute. Decisions should be based on exceeding a relative number, rather than a specific number of degrees. For example, if the temperature converter is adjusted for an output of 1.050 volts at 25° C and the voltage decreases by 2.3 mV/°C, the program can be written to do something when the temperature is 20° C, or 1.039 volts. The 1.039 volts is related to the temperature but is not actually in degrees.

Figure 2F illustrates a joystick (or two independent potentiometers) for use in game programs.

A BASIC program to play the game SAM is shown in Table IV. Note that the data written to the output port (EXTOUT) is in decimal, rather than in hex. The REM statements should help explain the program. Table V illustrates a 4-channel DVM program, which is also written in BASIC.

Construction. An actual-size etching and drilling guide and a component-installation diagram for the A/D converter are shown in Fig. 3. During assembly, note the polarity of *C4* and, if you wish, use sockets for the IC's. Note also that there are provisions on-board for optional inverters (IC's or discrete transistors); these can be Wire Wrapped.

When installing the IC's, observe the usual precautions for handling MOS devices. Since the 5-volt power supply is also used as the reference, make sure it is well regulated and stable. After assembly, adjust *R1* for as near to an exact 2.000 volts at pin 16 as possible.

If your system employs an active high strobe, use an inverter. Flat ribbon cable can be used to interconnect the converter to the host computer. If desired, a 16-pin socket can be mounted at one of the extra positions on the board, and, with Wire Wrap, it can be used to make the external connections instead of the edge connector shown.

Testing. After assembling the board

TABLE V—4-CHANNEL DVM PROGRAM

```
4-Channel DVM Program
Central Data Basic (2650), Version 1.2

000  RESTORE
010  DATA 1, 17, 33, 49, 1, 2, 18, 34, 50, 2, 4, 20, 36, 52, 3, 8, 24, 40, 56, 4
020  READ A, B, C, D, E        REM A=Ch#Digit 1:B=Ch#Digit 2:C=Ch#
                                    Digit 3:D=Ch#Digit 4:E=Ch#
030  GOSUB 100
040  IF E=4 GOTO 000
050  GOTO 010
100  EXTOUT 0, A               REM sets up I/O port Ch&digit
110  S=SIN(1)                  REM delay for A/D settling time
120  EXTIN 0, Z                REM reads port 0 into Z
130  EXTOUT 0, B
140  EXTIN 0, Y
150  EXTOUT 0, C
160  EXTIN 0, X
170  EXTOUT 0, D
180  EXTIN 0, W
190  PRINT@E, 5'CHANNEL#'#E'='#(W*1000+X*100+Y*10+Z)' MILLIVOLTS'
                               REM prints at line E, character position 5,
                                    channel #E=(voltage) MILLIVOLTS
200  RETURN
300  STOP
310  END
```

and adjusting *R1* for the 2-volt reference, load a driver program and check the system for accuracy. If the data appears to be unstable, check the 200-ms delay between the output port strobe and the input port strobe. You may have to vary the values loaded into the DLY routine until the correct delay is obtained. This delay is required only when the channel information is first changed. If only one channel is used, the delay need be used only the first time the channel is selected.

The 6800 program shown is not exact; it is given here as an example of a driver routine for the 6800 CPU. The 8080 program, tested in an 8080-based computer, uses I/O port 10H and a delay (DLY) routine for a 2-MHz system. The CMA and OUT-OFFH instruction invert the data and write it into the front panel. Location 4034 reserves one byte of memory that can be used to store the hex data, if desired. The 2650 program was written for and tested on a Central Data computer. The port used here was OOH, and the DLY routine is for a 1.25-MHz clock.

The A/D converter offers the computer user an inexpensive way for his computer to "communicate" with the analog happenings that dominate our lives. It offers a multitude of ways of sensing and measuring analog data not possible in a simple keyboard-entry system. ◇

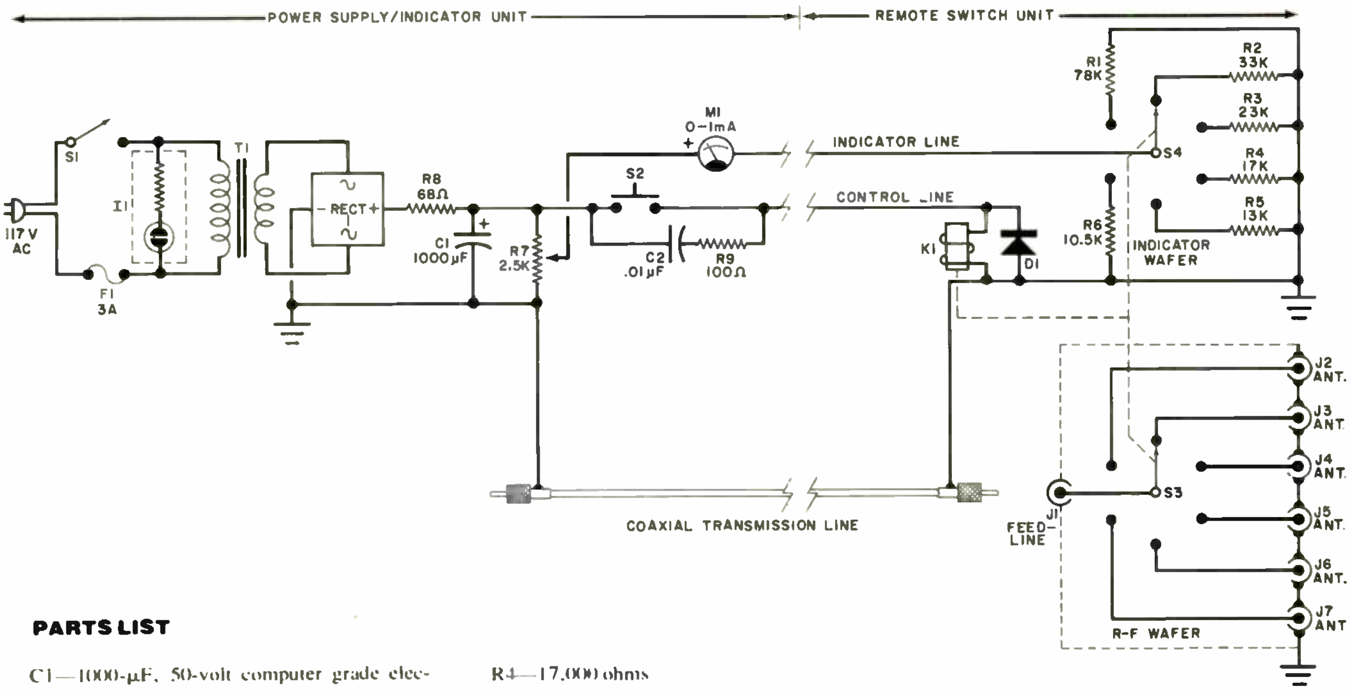
BY BUD WEISBERG, K2YOF

BUILD A REMOTE ANTENNA SELECTOR SWITCH

Low-cost, reliable switch permits selecting from among six antennas

Erecting multiple antenna systems offers the communications buff increased operating flexibility and frequency coverage. Unfortunately, it can also add appreciably to station cost and complexity—especially when the antennas require separate feedlines. Presented here is an alternative to a large investment in coaxial cable—a low-cost, remotely controlled coaxial switch.

The Remote Antenna Selector Switch enables the user to quickly select one of six antennas. Equally important, it provides a silent, reliable indication of the selection without any need for relay-holding current or the imposition of dc or a-f control signals on the feedline. The project can be assembled from inexpen-



PARTS LIST

C1—1000-μF, 50-volt computer grade electrolytic
C2—0.01-μF ceramic disc
D1—1N4003 rectifier
F1—3-ampere fast-blow fuse
I1—110-volt neon pilot light assembly
J1 through J7—SO-239 coaxial connector
K1—12-position rotary stepping solenoid with 24-to-28-volt dc coil (Ledex Series 5 or equivalent)
M1—0-to-1mA meter movement
The following are ½-watt, 5% tolerance carbon composition fixed resistors.
R1—78,000 ohms
R2—33,000 ohms
R3—23,000 ohms
R4—17,000 ohms
R5—13,000 ohms
R6—10,500 ohms
R7—2500-ohm wirewound potentiometer
R8—68-ohm, 1-watt, 10% tolerance fixed carbon composition resistor
R9—100-onm, ½-watt, 10% tolerance fixed carbon composition resistor
RECT1—100-PIV, 4-ampere modular bridge rectifier
S1—5-ampere spst switch
S2—5-ampere, normally-open, momentary contact pushbutton switch
S3—11-position, 1-pole ceramic rotary switch (Centralab No. 2503 or equivalent)
S4—11-position, 1-pole phenolic switch wafer (Centralab No. JD or wafer from No. 1403 switch)
T1—24-to-28-volt ac, 2-ampere transformer (Radio Shack No. 273-1512 or equivalent)
Misc.—Suitable enclosures, 4" × 4" × 2" (10.2 × 10.2 × 5.1 cm) aluminum utility box, coaxial cable and PL-259 connectors, ¼" (6.4-mm) flexible shaft coupling, 2- or 3-conductor cable, machine and self-tapping hardware, silicone cement, PVC tape, No. 14 copper wire, solder, etc.
Note—Suitable surplus stepping solenoids are available from several sources.

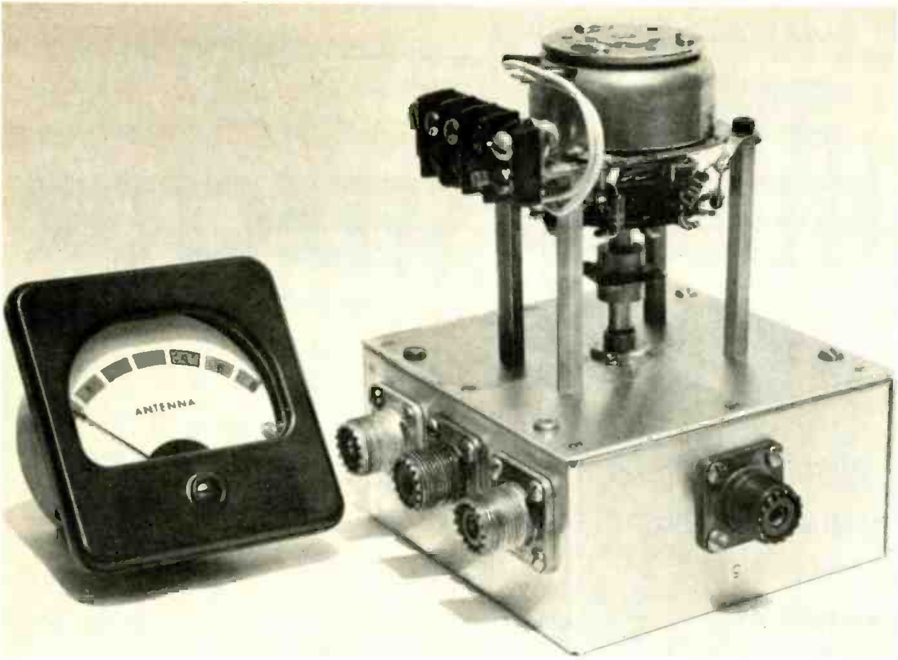


Fig. 2. Photo of the remote switch unit and antenna selection indicator.

sive surplus and junk-box parts and gives a level of performance rivalling that of commercial products costing much more.

About the Circuit. A schematic diagram of the Remote Antenna Selector Switch appears in Fig. 1. Upon the application of line power, electrolytic capacitor *C1* draws charge from stepdown transformer *T1* through bridge rectifier *RECT1* and resistor *R1*. When momentary pushbutton *S2* is depressed, *C1* discharges via the coil of *K1*, a 12-position rotary stepping solenoid. Eleven-position rotary switches *S3* and *S4* are driven by the shaft of *K1*, so the switches advance one position when the solenoid is energized.

In this project, only alternate switch contacts are employed. The solenoid must therefore be stepped *twice* to advance the switches to the next position. Wafer *S3* performs the antenna switching function. The other wafer, *S4*, is part of the indicator circuit, as are fixed resistors *R1* through *R6*, potentiometer *R7*, and milliammeter *M1*. As *K1* rotates the switch shafts, the effective series resistance between the negative side of *M1* and ground varies. This causes the meter movement to deflect and indicate the antenna selection on a modified meter scale. If the solenoid is stepped only once, the meter will read OFF, indicating that *S2* must be closed once more to advance the mechanism to the next antenna position.

Construction. The Remote Antenna Selector Switch comprises two units, the switch proper, shown in Fig. 2, and the power supply which appears in Fig. 3. Also shown in Fig. 2 is the position indicating meter, which can be built into an enclosure with the power supply or mounted on a separate panel.

The power supply is relatively simple and is most easily constructed using point-to-point wiring techniques. A barrier terminal strip such as that mounted on the prototype power supply's chassis will facilitate interconnections with the power line, switches and solenoid. Due to the amount of charge it must hold, capacitor *C1* must be a high-grade component such as a computer-grade electrolytic. Similarly, the pushbutton switch employed as *S2* must be able to handle the substantial current flowing when *C1* discharges through *K1*.

The meter scale will have to be relabelled. The zero line should be labelled the OFF position, the full-scale mark labelled position 6, and the remaining five numerals spaced equally between these two extremes. A more or less sensitive meter movement can be used, but in the former case larger values will be required for *R1* through *R6* and in the latter case smaller values. Non-standard resistor values can be obtained by combining standard ones either in series or parallel.

The remote unit shown in Fig. 2 consists of a solenoid driving two rotary switches. In the author's prototype, the solenoid is a Ledex Series 5 type with a 1-7/8-inch (4.8-cm) diameter case. It is available from most industrial suppliers. Surplus solenoids can be obtained from

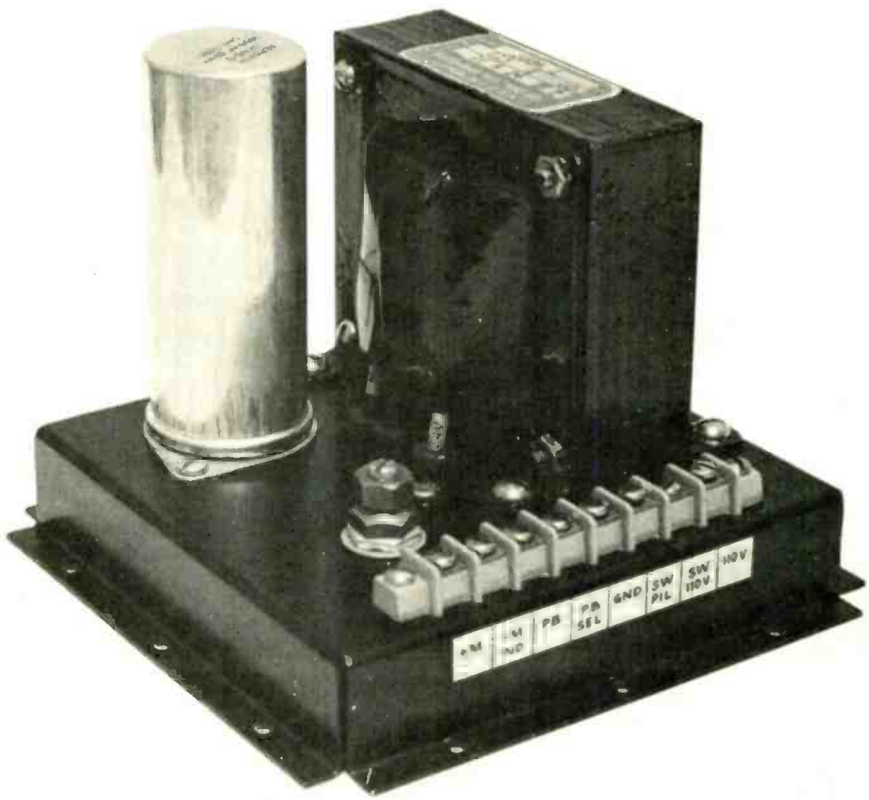


Fig. 3. Photo of the power supply unit.

several sources.

Solenoid *K1* and phenolic switch wafer *S4* are mounted in the center of the utility box's top cover using four 2¼-inch (5.7-cm) tapped metal standoffs, as shown in Fig. 2. Ceramic wafer switch *S3* is mounted inside the utility box and its shaft is coupled to that of the solenoid by an all-metal flexible coupling with dual setscrews on each hub. (These are required to withstand the high torque generated by the solenoid.)

Because the solenoid provides positive indexing, the detent and stop on *S3* must be carefully broken off to reduce drag and allow continuous rotation. Also, alternate contacts on the switch's ceramic wafer should be removed by *very gentle* prying or filing to leave six contacts plus the wiper contact.

The wiring of this switch is shown in Fig. 4. To minimize impedance mismatch, two low-inductance rings are mounted on opposite sides of the ceramic wafer. Form two 2½" (6.4-cm) inner diameter rings from 8" (30.3-cm) lengths of soft-drawn copper wire and hammer the rings flat. Again adjust the inner diameter to 2½", and trim away the excess at the overlap. Butt-join and solder the rings closed.

Partially hidden in Fig. 4, the front ring is soldered to the lug of *S3*'s wiper and to a short length of tinned No. 14 copper wire. The other end of this wire should be soldered to the inner conductor pin of *J1*, the FEEDLINE SO-239 coaxial jack. The rear copper ring is soldered to lugs held in place by the switch assembly screws. A ¼-inch (6.4-mm) insulated spacer should be placed under each of these solder lugs to position the two rings about 7/16 inch (11.1 mm) apart. This might require the substitution of longer screws for those used by the switch manufacturer.

The inner conductor pins of the remaining SO-239 jacks (*J2* through *J7*) can now be connected to the appropriate contact lugs of *S3* via short lengths of tinned No. 14 copper wire. Install a solder lug at each jack location, securing it to the aluminum utility box with one of the four pairs of screws and nuts holding each jack in place. Next, connect one end of a short length of tinned No. 14 copper wire to the solder lug at *J1*. Solder the other end of the wire to the rear copper ring. Repeat this procedure for the remaining jacks (*J2* through *J7*).

Note that the switch shown in Fig. 4 has a metallic ring which shorts out all unselected switch contacts. The author's original intention was to utilize this ring to ground all unselected antennas. This idea was discarded, however, because of the possibility of flashover during transmissions at medium amateur power levels (several hundred watts). In CB, QRP amateur, and SWL applications, however, there is no danger of flashover. Accordingly, those readers whose use of the antenna switch falls into one of the three categories mentioned might want to incorporate this feature for lightning protection. Those who want to do so should not procure the switch type specified in the parts list because it lacks a shorting ring. Rather, they should obtain a switch having such a ring.

Before tightening the shaft coupling's setscrews, make sure that the wiper of *S3* is properly aligned with that of *S4*. Each wiper should be touching the corresponding contact on each switch wafer. A drop of Loctite or nail polish on each screw head and nut will keep the mechanical assembly of the Remote Antenna Selector Switch secure.

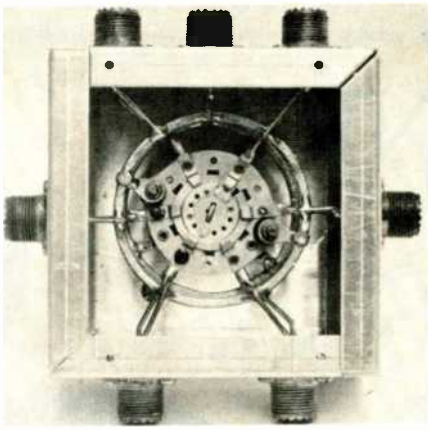


Fig. 4. Photo of the r-f wafer switch shows how two copper rings are used to minimize impedance mismatch.

Adjustment. Interconnect the power supply and switch units with a length of two- or three-conductor cable. The cable should have the same length as that required to run from the remote switch unit to the power supply in the finished installation. It can, in fact, be the same cable. Note that the circuit shown in Fig. 1 employs the braid of the coaxial feedline as a return path for the solenoid and position indicator circuits. This allows the use of a two-conductor control cable. If a separate return path is preferred, a three-conductor control cable must be used. For cable lengths up to 50 feet, No. 20 conductors can be used. Longer control cable lengths necessitate the use of No. 18 or 16 conductors.

Close power switch *S1* and wait a few seconds so that *C1* can acquire a full charge. Then momentarily close *S2*. The solenoid should step and advance one position. Note, however, that *S2* must be closed again to advance the switch to the next antenna position. With the component values specified in the schematic and parts list, you should be able to step *K1* once every two seconds or so. If a faster stepping rate is desired, reduce the value of *R8*.

Adjust potentiometer *R7* so that · 10 volts appears between its wiper and ground. The meter will then correctly indicate the position of the antenna position switch. If *K1* is stepped only once, the meter will read OFF, indicating that the switch is between antenna positions.

Installation and Use. The location of the remote switch unit depends on the particular application. If directly exposed to the elements, the remote unit should be housed in a plastic enclosure of a suitable size. All joints, holes and screw heads should be treated with silicone cement to weatherproof the assembly. Coaxial connectors soldered to the antenna and main downlead cables should be thoroughly taped with PVC tape and/or liberally treated with silicone cement because these PL-259 plugs are not weatherproof. Failure to do this will result in premature deterioration of the coaxial feedlines.

As mentioned earlier, the Remote Antenna Selector Switch does not ground unselected antennas. Therefore, it is advisable to insert lightning arrestors in the main downlead and the switch-to-antenna feedlines of any antennas which are not by virtue of their construction at dc ground.

This project was designed to provide reliable remote antenna selection without introducing a significant impedance "bump" and consequent standing wave ratio on the coaxial line running to the radio shack. If switch *S3* and the coaxial jacks have been wired as suggested in this article, the switch can be used through vhf with good results. Remember that the solenoid must be stepped twice to advance the switch to the next antenna position. (Even if you forget, the meter will remind you by displaying an OFF indication.) During idle periods (the bulk of the time), the supply unit can be used to power other intermittent control projects formed around inexpensive surplus or industrial 24-volt relays and stepping solenoids. ◇

EXPERIMENTING WITH CIRCULAR SWEEP

Circular-sweep converter provides fascinating scope displays.

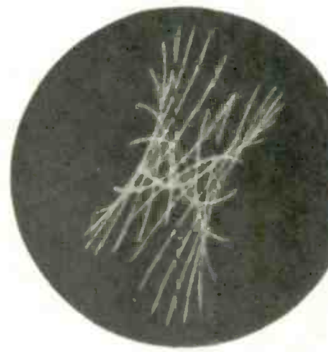
BY RANDALL K. KIRSCHMAN

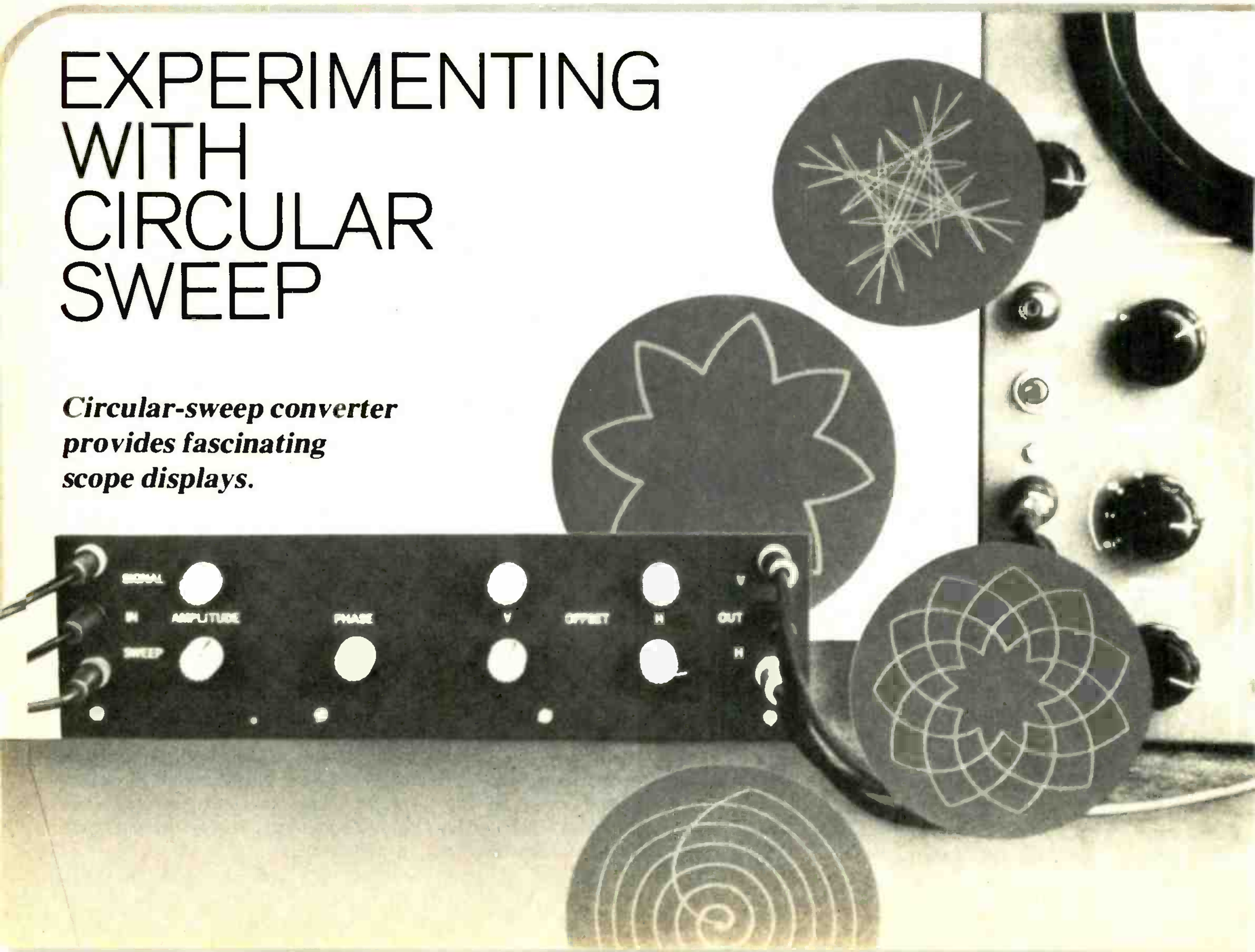
THE USUAL method of displaying waveforms on an oscilloscope is to sweep the beam horizontally to provide a linear time-base and then deflect it vertically with the waveform to be displayed. In this article, we will discuss another type of display—one in which the beam is swept in a circle and deflected radially (inward and outward from the center) by the waveform to be displayed. This method, called "circular sweep," has some practical advantages. Since the sweep baseline is a closed circle, there is no retrace; and, compared with linear sweep, the baseline can be made longer for an oscilloscope screen of a given size. However, in the author's opinion, practical considerations are of secondary importance to the fact that displaying waveforms with circular sweep creates all sorts of fascinating patterns and effects.

The circular-sweep technique has been used for many years, but early methods were usually limited in performance or were too impractical for the average experimenter. Now, however, with just four IC's, you can make a high-quality circular-sweep converter that connects to the input terminals of a conventional oscilloscope. No modifications of any kind need to be made to the scope.

How It Works. To move the oscilloscope beam in a circle and form the sweep baseline, two sine waves having a 90° phase difference are applied to the two inputs (horizontal and vertical) of the scope. The signal to be displayed is then combined with these two sine waves so that it deflects the beam in a radial direction. This is done with two analog multiplier IC's, as shown in Fig. 1.

An *analog multiplier* (or *operational multiplier*) is a circuit whose output voltage is the product of the two voltages fed into its inputs. The multipliers used here are of the *four-quadrant* type, which means that they can accurately





multiply for all combinations of positive and negative input voltages, a necessary feature for the converter circuit.

To understand how the converter works, think of each multiplier as an amplifier whose gain for the sweep sine wave passing through it is proportional to the voltage fed into its input (in other words, a voltage-controlled amplifier or VCA). The signal to be displayed, plus a constant dc voltage, is also fed to this input. Thus, if the signal is zero, the dc voltage will result in a fixed gain, causing the sine waves to be passed (point A in Fig. 2). This produces a circular baseline on the scope screen.

If the signal voltage increases in a positive direction, the gain of each multiplier is increased, causing the circle to become larger so that the trace is displaced outward from the baseline position (point B). On the other hand, if the signal goes negative, the gain is decreased, causing the trace to move inward (point C). The inward and outward displacement is proportional to the voltage level of the input signal. Thus the beam moves radially in correspondence with the instantaneous voltage of the input waveform, tracing out the waveform as it sweeps around the circle. The result is a circular-sweep display.

Another way of looking at the operation of the circuit is to realize that each multiplier is acting as a modulator. The sweep sine wave is the "carrier" which is amplitude-modulated by the signal to be displayed. The situation is unusual in that the modulating signal has a *higher* frequency than the carrier for most displays. Also, because four-quadrant multipliers are used, they can "overmodulate" without causing trouble. Instead of clipping the waveform, overmodulation causes the trace to go through the center and come out the other side, as will be shown later.

Circuit Description. The complete circuit of the converter is shown in Fig. 3. A 741 operational amplifier (*IC1*) amplifies and buffers the input signal, which is then fed to one of the "X" inputs of each multiplier (pins 3 of *IC3* and *IC4*). The constant dc offset is added by introducing an offset current into each multiplier (through *R14* and *R15* for *IC3*, *R20* and *R21* for *IC4*).

The sweep sine wave is inverted by another 741 op amp (*IC2*) and applied to the "Y" input of one of the multipliers (pin 5 of *IC4*). The direct sweep input and its inversion drive a phase-shifter consisting of *C5* and *R7* to produce a

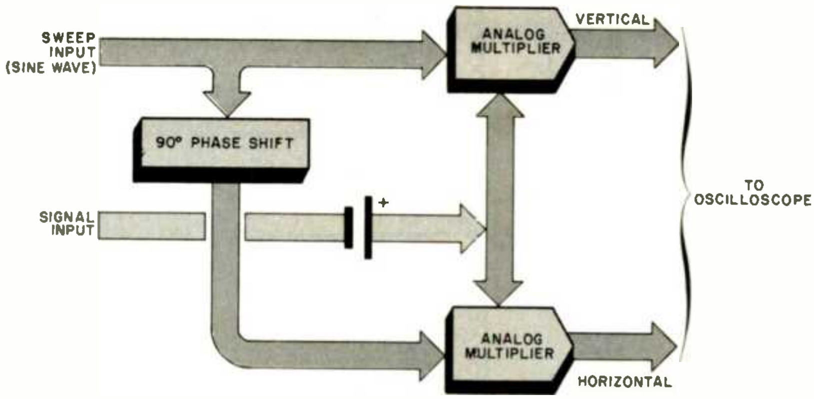


Fig. 1. Block diagram illustrates the basic operation of the circular-sweep converter.

sine wave shifted by 90°, which is then applied to the "Y" input of the other multiplier (pin 5 of *IC3*).

The output of each multiplier (pins 1 and 2 of *IC3* and *IC4*) is connected in a differential configuration to the input of an op amp which is contained in the same IC as the multiplier. The op amps provide amplification and level shifting. The output of each op amp is connected to the corresponding output of the converter. The signal path is entirely dc coupled to display signals with frequencies as low as a fraction of a hertz.

Construction. The converter can be built on perforated board, or assembled bread-board style like the prototype shown in Fig. 4. In either case, leads should be kept fairly short and neatly arranged to avoid high-frequency feedback through the multiplier IC's which have a bandwidth extending to several megahertz. All capacitors, except *C1* and *C2*, should be connected close to the multiplier IC's.

Parts values are not critical, but *R5* and *R6* should be the same value, as should *R22* and *R24*, *R23* and *R25*, *R26* and *R28*, and *R27* and *R29*. Also, the corresponding parts associated with *IC3* and *IC4* should be the same values (*C6* and *C8*, *C7* and *C9*, *R8* and *R9*, *R10* and *R16*, etc.) so that the vertical and horizontal channels of the converter will be matched. Resistors *R25* and *R29* should not be wired in permanently since their values may have to be adjusted slightly as explained in the next section. If sweep frequencies differing appreciably from 60 Hz are used, the values of *C5* or *R7* may have to be changed to get the proper phase shift of 90°. Though the XR-2208 IC is available in several versions, the least expensive, XR-2208CP, was used in the prototype.

The breadboard should be attached to a front panel similar to that shown in Fig. 4, with the appropriate markings. (Use press-on type or some similar means of identification.)

A dual power supply, such as that whose circuit is shown in Fig. 5, is required. Although the prototype used ±12 volts, any supply from ±10 to ±15 volts will work. The converter requires about 20 mA from each side of the supply. Batteries (9 V) can be used for testing purposes.

Checkout and Adjustment. After making sure that the power supply is generating the correct voltages, connect it to the main circuit. Set the SIGNAL AMPLITUDE (*R1*) and SWEEP AMPLITUDE (*R4*) controls for minimum resistance and the four OFFSET controls (*R12*, *R15*, *R18*, and *R21*) at approximately their midrange positions.

Measure the dc voltage between the V OUT connector and ground (center connector) and note that it should be under

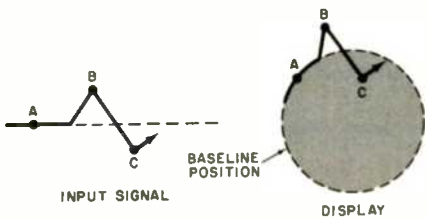


Fig. 2. Converter changes input (left) into circular display.

a few tenths of a volt, either plus or minus. If not, alter the value of *R25* until the minimum is obtained. Repeat this procedure for the H OUT connector, adjusting *R29* if necessary.

Connect the V and H OUT and center ground connectors to the vertical, horizontal and ground connectors, respectively, on the oscilloscope. Almost any scope will suffice if it has a vertical and

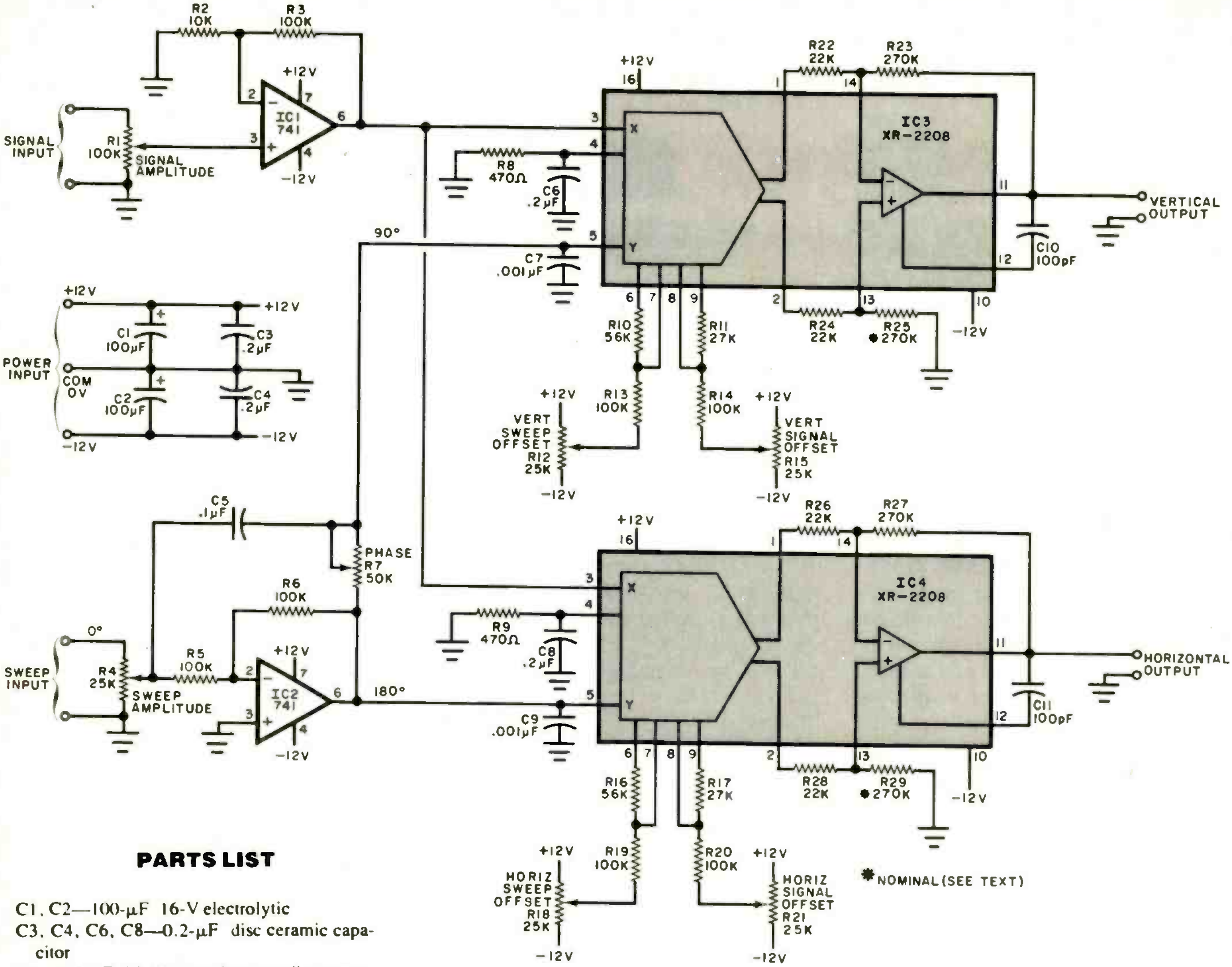


Fig. 3. Input is passed to two four-quadrant multipliers while sweep input to each multiplier is applied 90° out of phase.

PARTS LIST

C1, C2—100-µF 16-V electrolytic
C3, C4, C6, C8—0.2-µF disc ceramic capacitor
C5—0.1-µF Mylar capacitor (not disc ceramic)
C7, C9—0.001-µF disc ceramic capacitor
C10, C11—100-pF disc ceramic capacitor
IC1, IC2—741 operational amplifier (or one 747 dual op amp)
IC3, IC4—XR-2208 operational multiplier (Exar)
Unless otherwise noted, the following are ¼-W, 10% resistors:
R1—100,000-ohm potentiometer
R2—10,000 ohms
R3, R5, R6, R13, R14, R19, R20—100,000 ohms
R4, R12, R15, R18, R21—25,000-ohm linear-taper potentiometer
R7—50,000-ohm potentiometer
R8, R9—470 ohms
R10, R16—56,000 ohms
R11, R17—27,000 ohms
R22, R24, R26, R28—22,000 ohms
R23, R25, R27, R29—270,000 ohms (see text regarding R25 and R29)
Misc.—Circuit board; chassis or cabinet; IC sockets; knobs; binding posts or jacks; hardware; etc.

horizontal bandwidth of 50 kHz or more. If your scope has dc coupling, you can work with waveforms having very low frequencies. Ac coupling will, of course, still work. Set the scope vertical and horizontal sensitivities to about 0.4 V/cm (1 V/in.).

Apply the signal to be displayed and the sine-wave sweep to the appropriate input connectors on the converter front panel. The signal to be displayed can be obtained from any waveform source, such as an audio oscillator. Its frequency should be five or ten times that of the sweep. The sweep sine-wave source can be from a conventional 6.3-V transformer or from an audio generator set to approximately 60 Hz. In either case, a good-quality sine wave should be used for best results. Keep both signal and sweep voltages between ±10 volts peak to avoid possible damage to the input integrated circuits.

Keeping the SWEEP AMPLITUDE (*R4*) at a minimum, turn up the SIGNAL AMPLITUDE (*R1*). This will probably produce a line on the scope screen. If excessive input amplitude is used, the converter will be overdriven and abrupt "glitches" will appear on the CRT. Adjust the V OFFSET sweep control (*R12*) and H OFFSET sweep control (*R18*) to reduce the line to a point.

Turn the SIGNAL AMPLITUDE (*R1*) to its minimum position, and adjust the SWEEP AMPLITUDE (*R4*) about half-way up (avoid overdrive). Then adjust the V OFFSET signal control (*R15*) and H OFFSET signal control (*R21*) near their maximums. Adjust PHASE (*R7*) and the scope vertical and horizontal gain controls until a circle approximately one third of the CRT diameter is formed on the screen.

Leave SWEEP AMPLITUDE (*R4*) where

it is, and adjust SIGNAL AMPLITUDE (*R1*). One of two things should occur. You will get either a circular sweep pattern or a diamond-shaped pattern similar to that shown in Fig. 6. If you get the diamond pattern, adjust *R21* to the opposite end of its range to get the circular pattern. This pattern may not be symmetrical. If not, adjust the V OFFSET signal control and the scope vertical gain control (or the H OFFSET signal control and scope horizontal gain).

The PHASE (*R7*), V OFFSET (*R12*) and H OFFSET (*R18*) may also need touching up. Experimenting with the converter front-panel controls will establish the best settings for maximum symmetry and minimum distortion. The "double star" pattern formed by a triangular waveform (Fig. 8C) is a good pattern to use for final adjustments.

When the above steps have been completed, the converter is properly adjusted for circular sweep.

Fig. 6. Diamond-shaped pattern results when offset controls are at opposite settings.

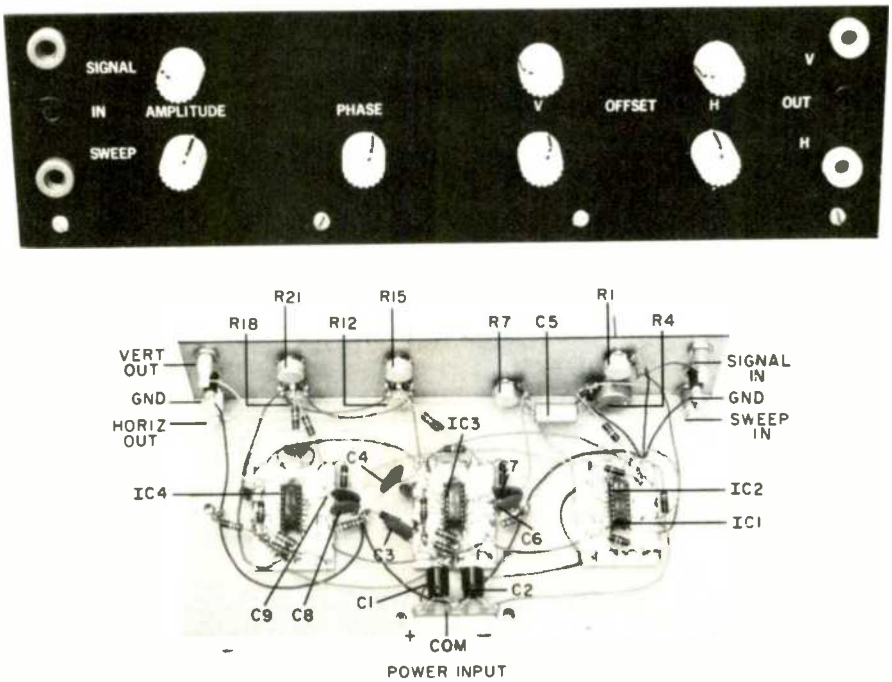


Fig. 4. Photo at top shows front panel of prototype. Below is prototype breadboard. Pc board can be used.

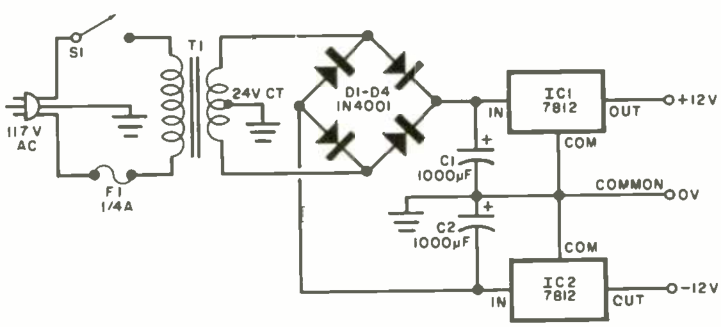


Fig. 5. The dual power supply uses both positive- and negative-voltage regulator integrated circuits.

Use. Some familiar waveforms displayed with the circular sweep converter are shown in Fig. 7. In each case, the waveform frequency was adjusted to give a pattern with a whole number of cycles. The waveforms are sine (Fig. 7A), triangle (Fig. 7B), sawtooth (Fig. 7C), and square (Fig. 7D). As the amplitude of the waveform is increased, the inside of the trace will meet at a point in the center (if the converter has been adjusted properly), as illustrated in Fig. 8A for the triangle waveform. Increasing the amplitude further causes the trace to go through the center and come out the opposite side as shown in Fig. 8B (even number of cycles) and Fig. 8C (odd number of cycles).

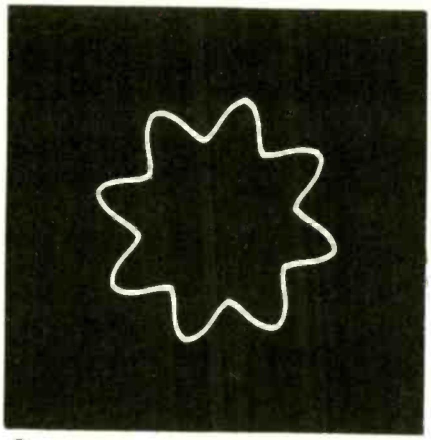
The pinwheel pattern in Fig. 9A and the spiral in Fig. 9B are both made with sawtooth waveforms. In Fig. 9A, the waveform amplitude is adjusted so that the traces meet in the center. In Fig. 9B, a low-frequency sawtooth is used. All the patterns illustrated in this article were made using a 6.3-V filament transformer to supply the 60-Hz sweep. The waveforms were obtained from a 8038 waveform generator IC, hooked up as shown in Fig. 10. Hundreds of other patterns can be produced with these basic waveforms. If you exhaust those possibilities, try mixing the outputs of two (or more) waveform generators.

One of the most fascinating displays is that made by music waveforms. Whatever else you do with the converter, be sure to try this. Simply connect the audio from a radio, tuner, phono, etc. to the SIGNAL IN jack. The result is a kaleidoscopic succession of patterns synchronized to the music. No examples are shown because the patterns and effects cannot be satisfactorily captured by still

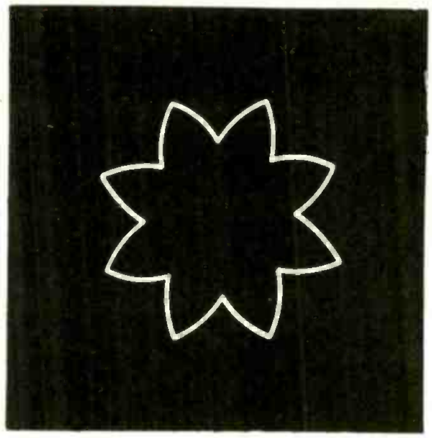
POWER SUPPLY PARTS LIST

C1, C2—1000-µF, 25-V electrolytic
D1 through D4—Rectifier diode (1N4001 or similar)
F1—¼-A fuse
IC1—Positive 12-V, 100 mA or greater voltage regulator (7812 or equivalent)
IC2—Negative 12-V, 100-mA or greater voltage regulator (7912 or equivalent)
S1—Spst power switch
T1—24-V center-tapped, 100 mA or greater transformer

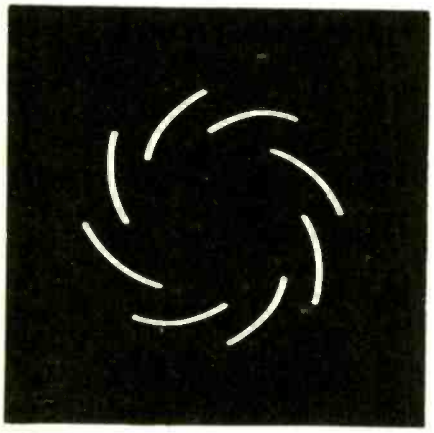
Fig. 7. Appearances of sine (A), triangle (B), sawtooth (C), and square (D) waveforms as displayed by circular-sweep converter system.



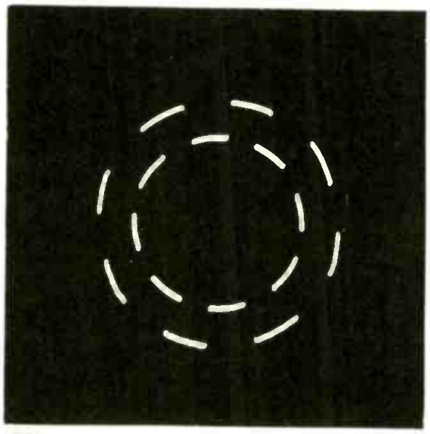
A



B

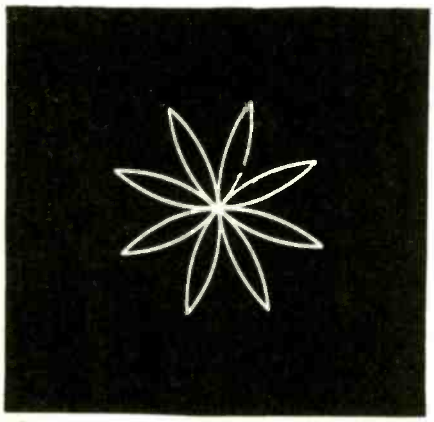


C

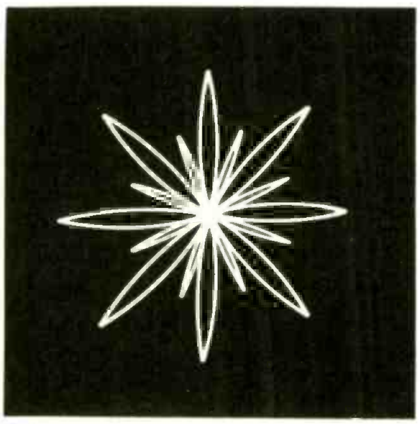


D

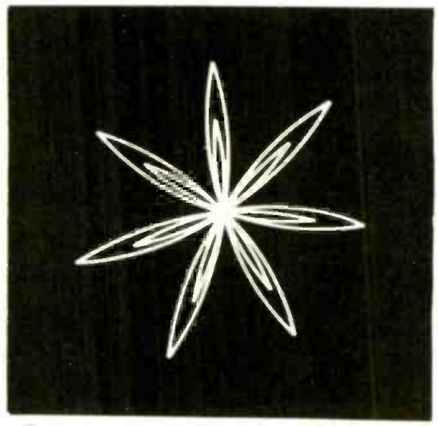
Fig. 8. Increasing the amplitude of a triangle waveform causes trace to meet in center (A) and come out opposite side with even number of cycles (B) and odd number of cycles (C).



A



B



C

photography. If you use an FM station as the source you may need to insert a low-pass filter (Fig. 11) between the source and SIGNAL IN to eliminate the multiplex and SCA subcarriers. Speech also makes an interesting display.

Frequency Comparison. Using an oscilloscope in the conventional manner, the frequencies of two waveforms can be compared with Lissajous figures. In an analogous way, frequencies can be compared using circular sweep. For example, the traces in Fig. 7 all show eight complete cycles of the waveform, which means that the signal goes through eight cycles while the sweep goes through one cycle. Since a 60-Hz sweep was used, the signal frequency must be 8 times 60 Hz, or 480 Hz. Fig. 9B shows almost the opposite situation. Here the sweep goes through seven cycles while the signal goes through only one cycle. The signal frequency is thus 60 Hz divided by 7, or about 8.43 Hz.

Sometimes the pattern will be more complicated, like the one shown in Fig. 12. It is still relatively easy to determine the frequency as illustrated by the following analysis of the pattern. Starting at one peak on the waveform and following the trace, the next peak that we come to is the fourth one over from the starting point. This means that the sweep goes around four times to make one complete pattern. Note also that there are 11 peaks in all, which means that there are 11 cycles of the triangle waveform in the pattern. Thus, the sweep-to-signal fre-

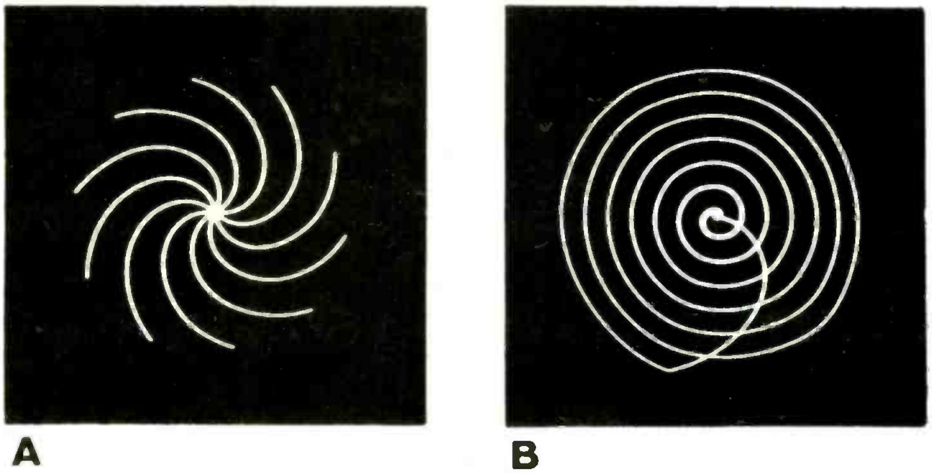


Fig. 9. Pinwheel (A) and spiral (B) patterns are produced by sawtooth waveforms of different frequencies.

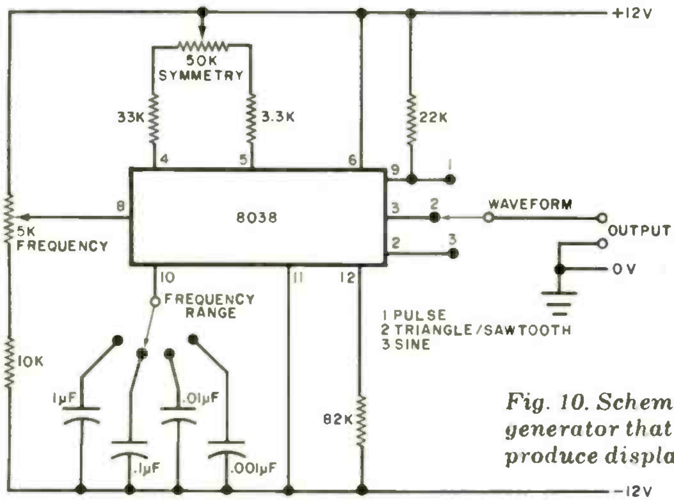


Fig. 10. Schematic of waveform generator that can be used to produce displays shown here.

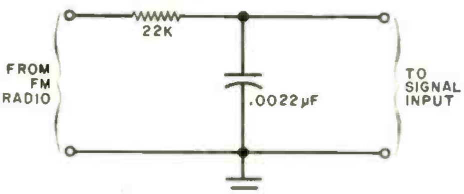


Fig. 11. Filter can be used to remove subcarriers when audio from FM stations is displayed.

quency ratio is 4:11. Since a 60-Hz sweep was used, this gives a signal frequency of (11/4) × 60 = 165 Hz.

The frequencies thus determined are exact only if the pattern is stationary. A rotating pattern indicates a slightly higher or lower frequency, depending on the direction of rotation.

Besides circular sweep, the converter can be used for other types of displays which may be less practical and more difficult to analyze but are just as interesting. For example, you can adjust *R15* (or *R21*) to the opposite end of its range to get the diamond-shaped display mentioned earlier (Fig. 6). For even more variety, all seven controls on the converter can be varied. Combine this with all the different waveforms and combinations which can be used as the signal or sweep and you should be kept busy for a while. Figure 13 illustrates a few possibilities. But be warned—you may become so engrossed that you abandon your color organ, computer graphics, and even television! ◇

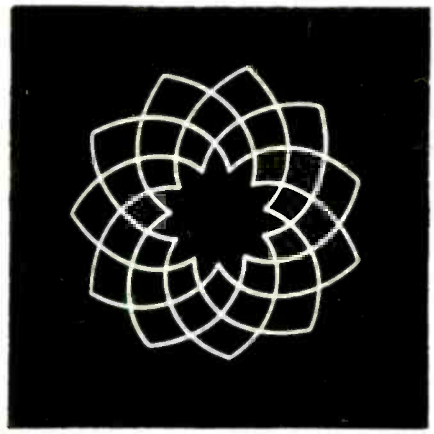


Fig. 12. Frequency comparison with circular sweep. Ratio of triangle to sine sweep is 11:4.

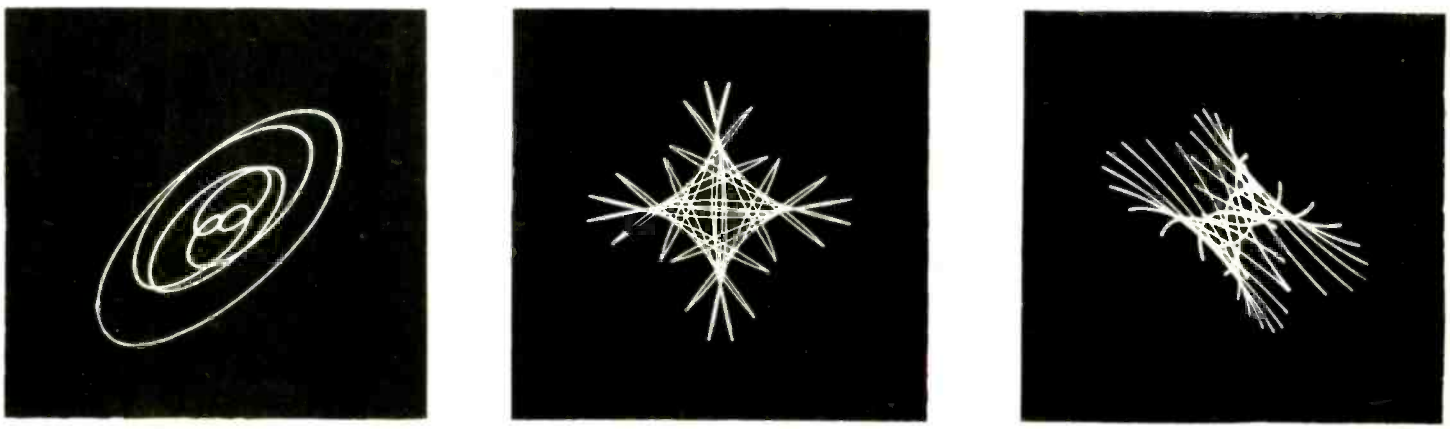


Fig. 13. Three imaginative examples of the thousands that can be generated with the circular-sweep converter.

BY PAUL E. MILLER

BUILD A STEREO BLEND CONTROL

Vary channel separation to suit your taste with this inexpensive circuit.

AUDIO designers usually try to maximize their products' stereo separation. There are times, however, when a measure of crosstalk between channels is desirable. For example, the disquieting "orchestra in the cranium" effect experienced with stereo headphones can be mitigated by reducing the program material's channel separation. The stereo blender described here allows the user to vary channel separation to suit his taste. Also, the two channels can be transposed with adjustable separation—left input to right output, and vice versa. The blender employs inexpensive components, and can be bypassed at the touch of a switch.

About the Circuit. The schematic diagram of the stereo blender is shown in Fig. 1. The heart of the circuit is contained in two variable voltage dividers, comprising *R1* through *R4* and *R9* for the left channel, and *R5* through *R8* and *R10* for the right channel. Input signals are applied to the voltage dividers via coupling capacitors *C1* and *C2* and voltage followers *IC1A* and *IC1B*.

A dual 10,000-ohm, linear-taper potentiometer is used for *R9* and *R10*. When the potentiometer wipers are at one extremity of their travel, the stereo separation and spatial location of the input signals are preserved. At the other end, there is still no introduction of crosstalk but the channels are transposed. Adjusting the wipers for the center of their travel gives a complete "blend," with both inputs mixed equally and fed to both outputs. Between the center and either extreme, partial blending of the two channels is obtained.

The voltage dividers have an insertion loss of approximately 4.7 dB. This loss is compensated for by the gain introduced by *IC2A* and *IC2B*. To ensure that the voltage divider losses and op amp gains cancel each other, resistance tolerances should be kept fairly close. If this is done, no audible change in volume will occur when the project is switched on or out of the signal path.

Another reason for using close-tolerance resistors lies in an important characteristic of the voltage dividers. That is, the overall output should remain constant regardless of the setting of the dual potentiometer BLEND control. Actually, the signal level at the output will be 3 dB below the input when the BLEND control is at its mid-position. But this loss is compensated for by the fact that the inputs are mixed equally and fed to each output. To maintain this relationship, actual resistances should be close to the components' nominal values.

Signals from the op amps are coupled to the output jacks via capacitors *C3* and *C4*, which also block any dc offsets generated by the gain stages. Fairly large values are required if output impedances are to be kept fairly low. At 20 Hz, a 1-µF capacitor has a reactance of approximately 8000 ohms. Therefore, the circuit should drive a load with a fairly high input impedance—a condition satisfied by most power amplifiers and tape deck record preamplifiers.

The output coupling capacitors must

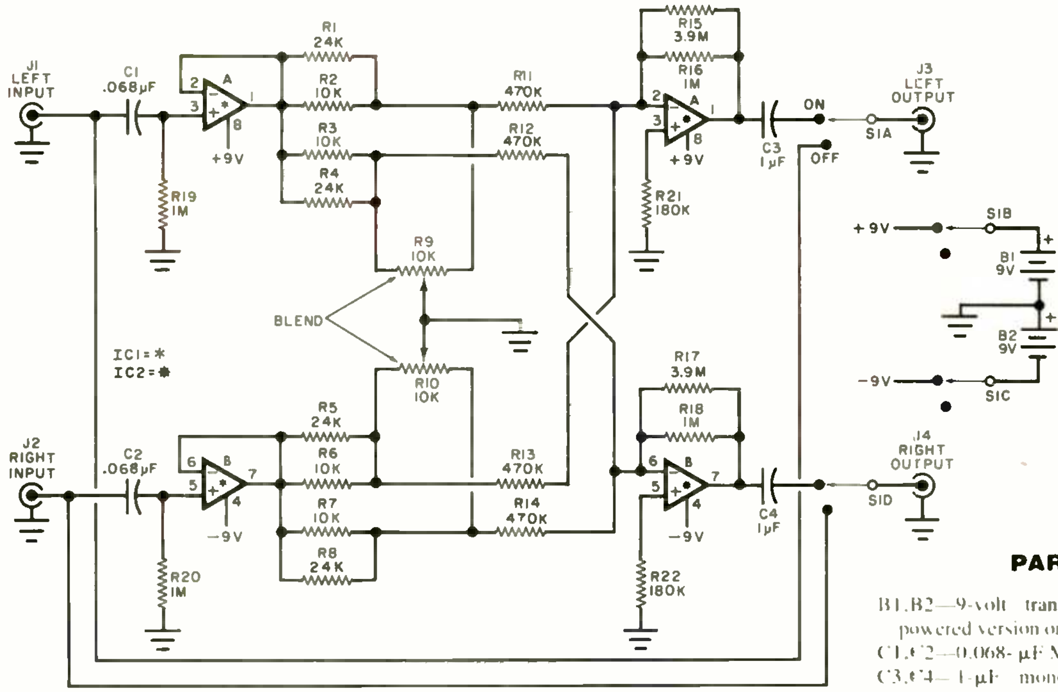


Fig. 1. Schematic diagram of the stereo blend.

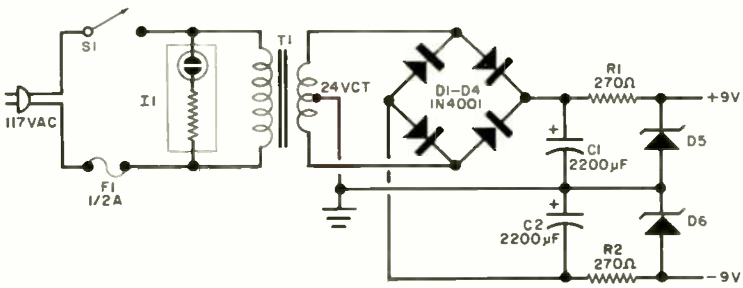


Fig. 2. Ac power supply features zener diode regulation.

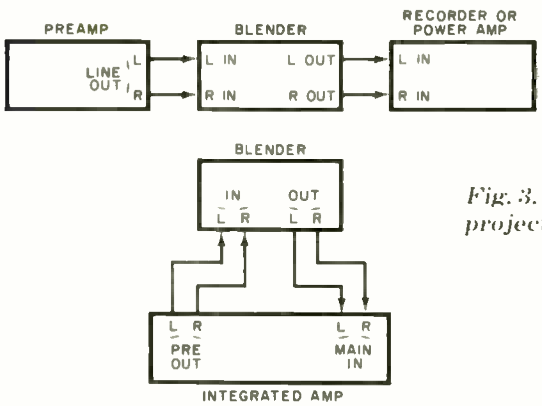


Fig. 3. Connecting the project to your system.

PARTS LIST

B1,B2—9-volt transistor batteries (battery powered version only)
C1,C2—0.068-µF Mylar capacitor
C3,C4—1-µF monolithic or nonpolarized electrolytic
IC1,IC2—MC1458 or 5558 dual op amp
J1 through J4—RCA phono jack
The following are 1/4-watt, 5% (or better) fixed resistors.
R1,R4,R5,R8—24,000 ohms
R2,R3,R6,R7—10,000 ohms
R11 through R14—470,000 ohms
R15,R17—3.9 megohms
R16,R18,R19,R20—1 megohm
R21,R22—180,000 ohms
R9,R10—dual 10,000-ohm, linear-taper potentiometer
S1—4pdt (battery powered version) or dpdt (line powered version) toggle or slide switch
Misc.—IC sockets or Molex Soldercons, printed circuit or perforated board, shielded or coaxial cable, hookup wire, suitable enclosure, battery clips, battery holders, machine hardware, solder, etc.

AC SUPPLY PARTS LIST

C1,C2—2200-µF, 25-volt electrolytic capacitor
D1 through D4—1N4001 rectifier
D5,D6—9.1-volt, 1-watt zener diode
F1—1/2-ampere fuse
I1—Neon indicator assembly with integral current-limiting resistor
R1,R2—270-ohm, 1/2-watt, 10% tolerance carbon composition resistor
S1—spst switch
T1—24-volt center tapped, 85-mA transformer (Stancor No. P8394 or equivalent)
Misc.—Line cord, fuse holder, terminal strips, strain relief, hookup wire, machine hardware, solder, etc.

be nonpolarized because the ac signals are not riding on a large dc level. The author suggests the use of monolithic capacitors because of their high capacitance-to-volume ratio. Other types can be used if space permits. Nonpolarized electrolytics, which are commonly used in speaker crossovers, are readily available in unit quantities.

Much smaller coupling capacitors are used at the project inputs. Although they have fairly high capacitive reactance at audio frequencies, the resistance of *R19* and *R20* and the very high input impedances of the voltage followers prevent significant signal attenuation.

Two 9-volt transistor batteries power the circuit of Fig. 1. Total current drain is fairly low, so fairly long battery life can be expected if the project is used intermittently. However, you might prefer to power the project from the ac line. A suitable regulated bipolar supply is shown schematically in Fig. 2.

In the battery-powered version, *S1* is a 4pdt switch. The circuit is inserted into the signal path and the batteries connected to the op amps when the switch is placed in its ON position. The batteries are disconnected and signals at the input jacks routed directly to the output jacks, effectively removing the project from the signal path, when the switch is placed in the OFF position. In the line-powered version, *S1* becomes dpdt switch and is used only to insert or remove the circuit from the signal path. To keep the line-power ac away from the low-level signal lines, a separate spst switch is used to control the primary of the power supply.

Construction. The circuit can be assembled on either a printed circuit or perforated board. Shielded wire or small diameter (RG-174-U) coax should be used for all signal leads. If the line-powered supply is to be housed in the same enclosure as the signal processing circuitry, the two should be physically isolated as much as possible. A metal utility box should be used to house the project.

Use. The blender should be connected to your audio system as shown in Fig. 3 by means of shielded patch cords terminated with suitable connectors. As mentioned earlier, it can be used to make listening through stereo headphones more enjoyable. The project also allows home recordists to introduce interesting special effects when taping program material. Imaginative users will no doubt find other applications. ◇

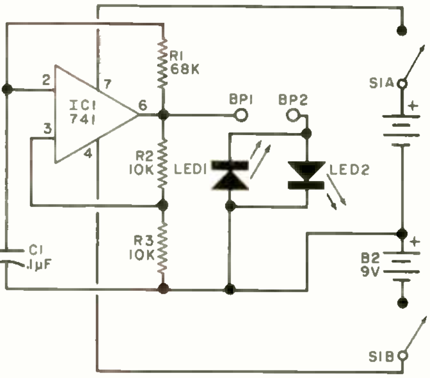
ONE-TOUCH DIODE TESTER

Identifies good/bad diodes, and tells which end is anode/cathode.

BY DAVID MARKEGARD

MOST electronics experimenters seem to have plenty of diodes in their junk boxes—either salvaged from old equipment or purchased at low bulk prices. The problem, usually, is to find out which ones are good, which are bad, and, in the case of the former, which end is which (cathode or anode). Of course, most diodes can be tested using a conventional ohmmeter. However, there are simpler ways if one is to use the diode checker described here. Simply by touching a diode's leads to its binding posts (in either polarity), you can tell whether or not it is good and identify the anode and cathode.

How It Works. Op amp *IC1* forms a simple square-wave oscillator whose output swings from almost full positive to full negative levels with respect to ground.



PARTS LIST

B1,B2—9-volt battery
BP1,BP2—Five-way binding post
C1—0.1-μF capacitor
IC1—741 op amp
LED1,LED2—Red LED (about equal brightness)
R1—68,000-ohm resistor
R2,R3—10,000-ohm resistor
S1—Dpst switch
Misc.—Perforated board, socket for IC1, battery holder, suitable enclosure, grommets for LED's, mounting hardware, etc.

IC1 is square-wave oscillator. Tested diode turns on either LED.

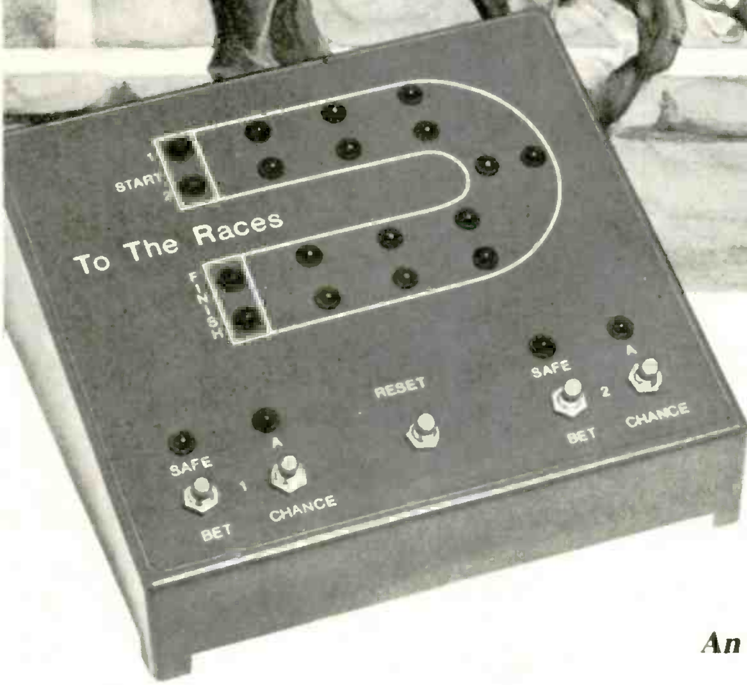
If a good diode is connected between *BP1* and *BP2* with its cathode toward *BP1*, *LED1* is forward biased and glows. *LED2* remains dark because it is reverse biased. If the diode is reversed so that its anode is at *BP1*, *LED2* glows and *LED1* is dark. With the LED's properly identified and placed close to *BP1*, an unknown diode lead connected to *BP1* is easily identified.

Construction. The circuit can be assembled on a small piece of perforated board and mounted in small enclosure along with the batteries in holders. The two binding posts and the power on/off switch should be mounted about an inch apart on top of the enclosure. Put the two LED's in rubber grommets near *BP1* and identify them properly.

Before installing the LED's, be sure they are of equal brightness. The values of *R1*, *R2*, *R3*, and *C1* can be varied if the specified values are not available—as long as the circuit oscillates.

Use. Connect a diode to be tested between the two binding posts. If only one LED glows, the diode is good and the glowing LED will identify the cathode. If both LED's glow, the diode is shorted. If neither LED glows, the diode is open.

Transistor junctions can be tested by connecting the collector to *BP1* and the base to *BP2*. If *LED1* glows and is brighter than *LED2*, the transistor is npn. If *LED2* glows, or is brighter than *LED1*, the transistor is pnp. ◇



TO THE ELECTRONIC RACES!

An exciting LED game to test the abilities of two players.

BY JAMES BARBARELLO

AGILITY, strategy, competition and luck—the classic ingredients of a race—are found in the electronic game, "To The Races." Designed for two players, the project has a race track formed from two rows of nine LED's each. Readily available CMOS digital and 556 dual timer IC's, and standard LED's are used in the game's circuitry. Four "C" cells form a power source. Total construction cost is about $25.

At the outset of a race, a RESET switch is closed and each contestant's START LED glows. Then four control LED's (one pair at each playing position) start blinking. Below each control LED, a pushbutton switch is mounted, one labelled SAFE BET and the other A CHANCE. The LED above the SAFE BET switch blinks about once every 3 seconds, and the LED above the A CHANCE LED about three times that rate. These LED's remain on for approximately ¼ second.

If a contestant closes one of the two pushbutton switches while the corresponding LED is glowing, he advances one position. This is indicated by the darkening of the LED at the position previously occupied and the turning on of the adjacent LED. The faster flash rate of the LED above the A CHANCE switch permits much quicker progression around the track, but a penalty is associated with the switch's use. If it is depressed while the corresponding LED is dark, that player's circuitry is reset and he is sent back to the starting position.

No such penalty is associated with the SAFE BET switch. Therefore, you must choose between the two pushbuttons wisely. You might want to take a chance initially and pull ahead. Once you have established an early lead, you can play it safe and use only the SAFE BET switch. The first contestant to reach the FINISH position is the winner. At that point, his opponent's pushbuttons are disabled, so no further moves can be made.

About the Circuit. The schematic diagram of To The Races is shown in Fig. 1. One half of *IC1*, a 556 dual timer, operates in the astable mode and provides clock pulses for control LED's *LED3* and *LED4*, which correspond to the SAFE BET switches (*S3* and *S4*). Clock signals for *LED1* and *LED2*, which

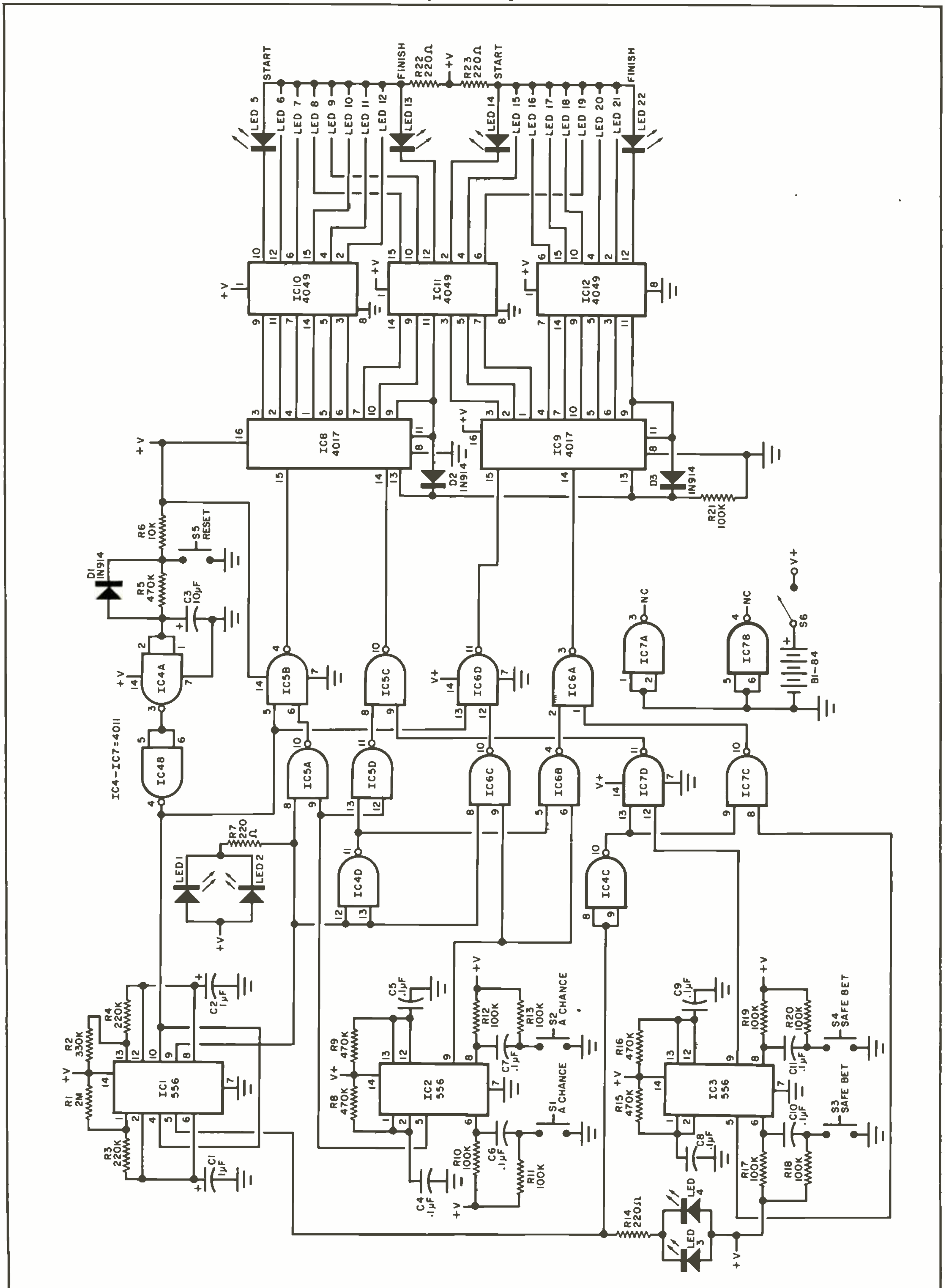


Fig. 1. Schematic of "To The Races" shows how circuit works. For Parts List, see opposite page.

PARTS LIST

B1 through B4—1½-V "C" cell
C1, C2—1-µF, 25-V electrolytic capacitor
C3—10-µF, 25-V electrolytic capacitor
C4 through C11—0.1-µF disc ceramic capacitor
D1 through D3—1N914 silicon diode
IC1 through IC3—556 dual timer
IC4 through IC7—4011 quad 2-input NAND gate
IC8, IC9—4017 decade counter/decoder
IC10 through IC12—4049 hex inverting buffer/converter
LED1 through LED22—20-mA red LED (TIL-32, or equivalent)
The following are ¼-watt, 10% tolerance carbon resistors:
R1—2 megohms
R2—330,000 ohms
R3,R4—220,000 ohms
R5,R8,R9,R15,R16—470,000 ohms
R6—10,000 ohms
R7,R14,R22,R23—220 ohms
R10 through R13, R17 through R21—100,000 ohms
S1 through S5—Normally open, momentary-contact pushbutton switch
S6—Spst toggle switch
Misc.—Battery holder, 14- and 16-pin DIP IC sockets, LED holders (NSL001) or rubber grommets, suitable enclosure, printed circuit or perforated board, hookup wire, solder, etc.
Note: The enclosure used, Model DMC-1, is available from Continental Specialties Corp., 70 Fulton Terrace, Box 1942, New Haven, CT 06509.

correspond to A CHANCE switches *S1* and *S2*, are generated by the other half of *IC1*, also operating in the astable mode. These clock signals are inverted by *IC4D* and *IC4C*, respectively. Contact debouncing for the A CHANCE and SAFE BET switches is performed by the four monostable multivibrators comprising dual timers *IC2* and *IC3*, respectively.

NAND gates *IC4A* and *IC4B* form a noninverting buffer on the RESET line. When RESET switch *S5* is closed, *C3* rapidly discharges through *D1*, causing *IC1*, *IC8*, and *IC9* to reset. Opening *S5* allows *C3* to charge through *R5* and *R6*. When the voltage across the capacitor reaches the logic one threshold (one half the 6-volt supply voltage), the output of *IC4B* goes high, thus enabling the previously reset IC's. Capacitor charging time is about two seconds. This delay allows one contestant to reset the game and prepare for play so that neither contestant gains an initial advantage.

If *S1* (A CHANCE) is closed while pin 9 of *IC1* is low and *LED1* and *LED2* are glowing, a pulse is transmitted through NAND gates *IC5C* and *IC5D* to pin 14, the CLOCK input of *IC8*, a 4017 CMOS decade counter/decoder. If pin 9 of *IC1* is high and *LED1* and *LED2* dark when

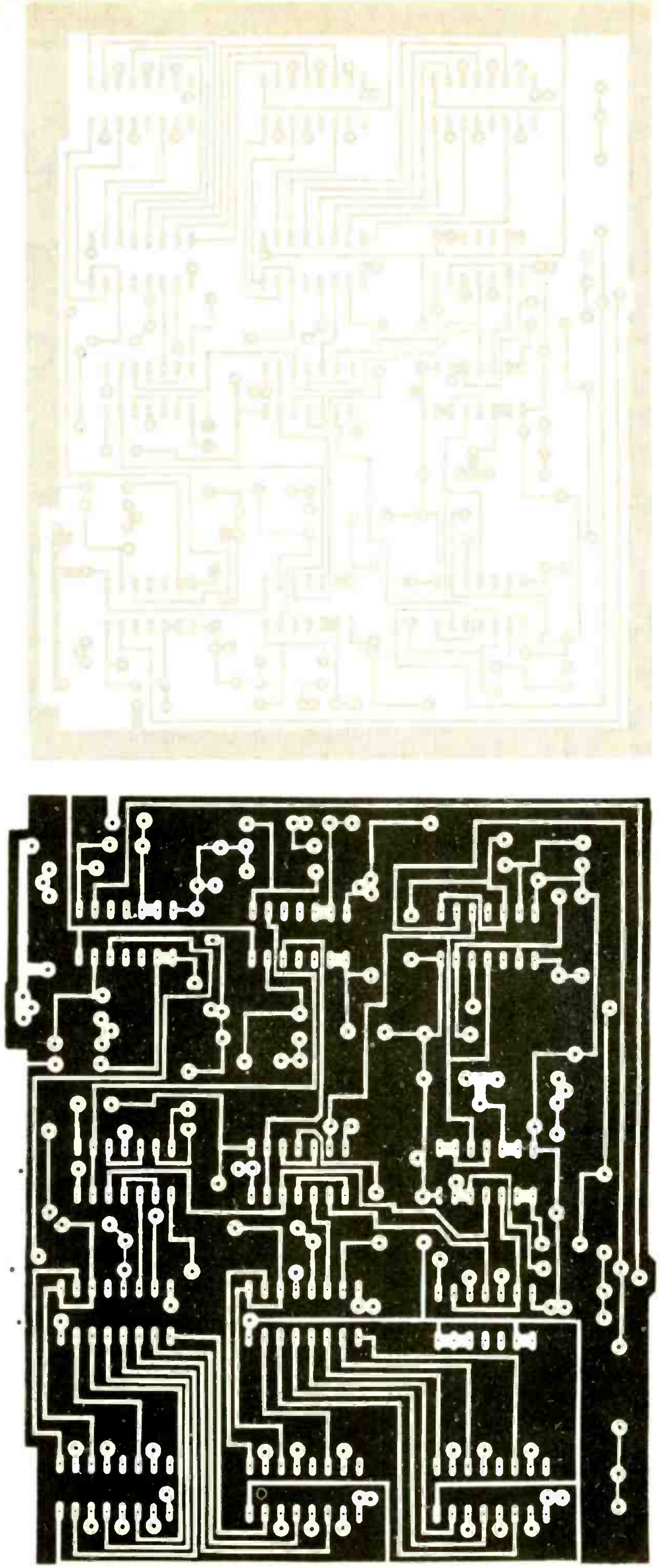


Fig. 2. Pc board etching and drilling and component (top) guides.

S1 is closed, the output of *IC5A* goes high and resets counter *IC8*. Closing *S4* (SAFE BET) when pin 5 of *IC1* is high and *LED3* and *LED4* are dark has no effect on pin 15 (the RESET input) of counter *IC8*. This functional description applies equally to *IC9*, *S2*, and *S3*, the other contestant's decade counter/decoder and switches, respectively.

As each counter receives clock pulses, it counts upward and the successive decimal outputs go high. The inverting buffers (*IC10A* through *IC12F*) connected to the counter outputs change state in turn, so that the counter outputs that are high drive the buffer outputs low. When buffer outputs are low, they sink current for the race track LED's (*LED5* through *LED22*) connected to them. Current limiting for the LED's is performed by *R22* and *R23*. Only one limiting resistor per row is required because only one LED per row is on at any time. When pin 9 of either counter goes high and FINISH *LED13* or *LED22* glows, the OR gate formed by *D2*, *D3*, and *R21* causes the ENABLE input (pin 13) of both counters to go high. This freezes the counters and prevents further triggering of either one.

Construction. Printed circuit (guides shown in Fig. 2) perforated board, or Wire Wrap techniques can be employed to duplicate the circuit. The use of IC sockets is recommended. Be sure to observe the polarities of all IC's, diodes, and electrolytic capacitors, and to exercise care when handling the CMOS devices. The author's prototype was housed in a Continental Specialties Corporation Model DMC-1 case. However, any enclosure large enough to house the components and battery power supply can be used. Drill and label the front panel of the enclosure using the photograph of the prototype as a guide. Use LED holders or rubber grommets to retain the LED's in place.

Use. Close power switch *S6* and RESET switch *S5* in that order. Both START LED's and the four control LED's will glow. Two seconds later, the control LED's will start to blink, signalling that play can begin. The "on" time of the LED's and switch conditioning one-shots have been chosen to be close to the average person's reaction time. Therefore, both contestants will have to watch the blinking LED's and anticipate when they will glow. After a few initial games, you will become adept at play and ready for serious competiton when you go "To The Races." ◇

Making Digital Electronic Clocks Immune to AC Flicker

BY ANDREW FRASER

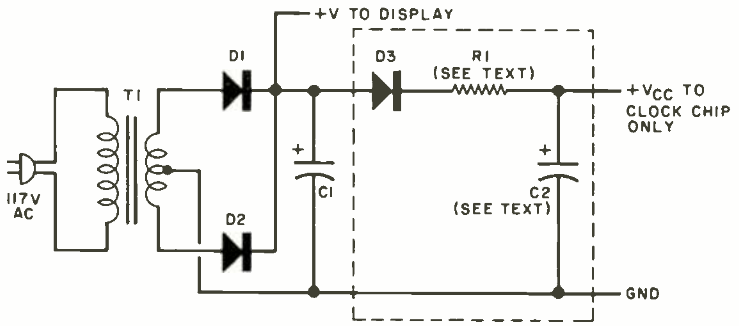
AN OCCASIONAL "flicker" on the ac line can interrupt power to a digital clock for up to a second. This can cause the filter capacitor in the clock's power supply to discharge through the displays to the point where the clock must be reset for accurate time. If you have encountered this problem, the circuit we present here can correct it.

A typical power supply for a digital clock consists of transformer *T1*, diodes *D1* and *D2*, and filter capacitor *C1*. The flicker-eliminator modification in this circuit consists of the components inside the dashed-line box. Now, power for the clock chip is obtained via *D3*, *R1*, and *C3*. When the ac line flickers, the current drawn by the displays will begin to discharge *C1* but the charge on *C2* will not go to the displays because under this condition *D3* will be in reverse bias. Hence, while the charge on *C1* might be quickly drawn off by the displays, the power delivered to the clock chip from the charge on capacitor *C2* will remain relatively constant.

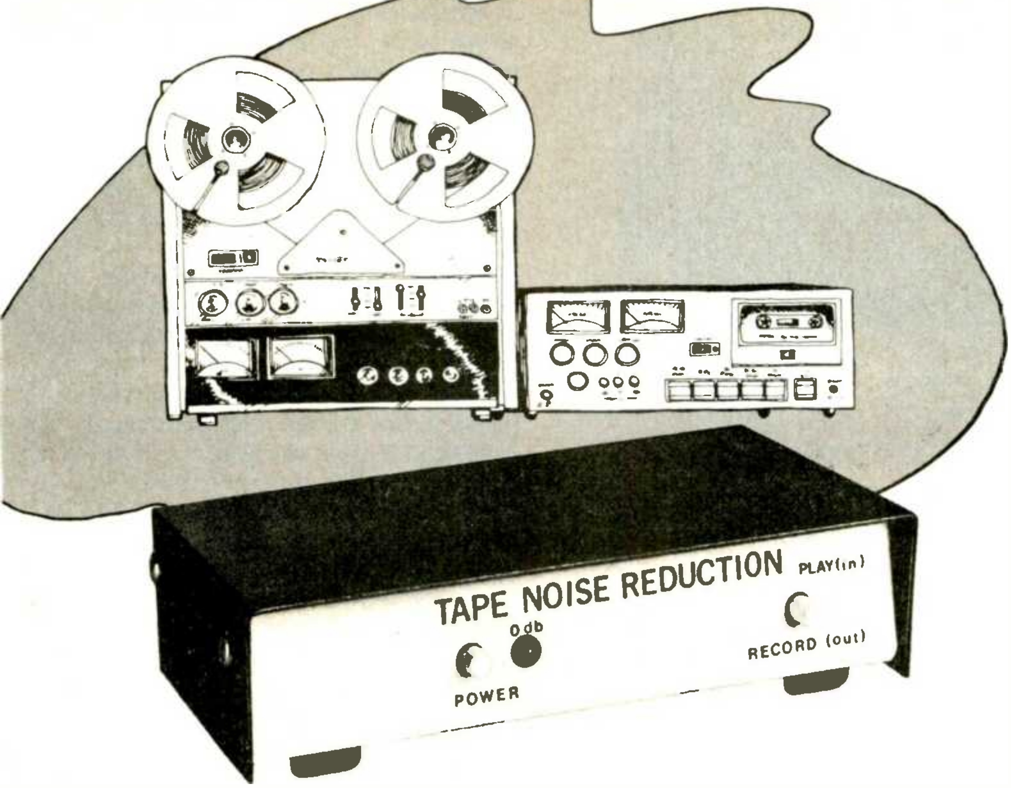
If a power supply normally delivers 12 volts and capacitor *C2* is a very high value (say 10,000 μF) and you are using an MM5316 clock chip that draws 5 mA and can operate down to 8 volts, *C2* can keep the clock chip (but not the displays) operating for several minutes. Most line flickers do not last this long. Also, this means that you can unplug your clock and move it to another location without having to reset it.

Resistor *R1* in the add-on circuit limits the current flow to *C2* during the charge cycle. If the power supply delivers 12 volts, a value of 100 ohms at 12 watts for *R1* will limit charging current to 120 mA. This allows *C2* to become fully charged in several seconds. If you use a lower-value capacitor for *C2*, *R1*'s value and power-handling capabilities can be reduced proportionately, or *R1* can be eliminated altogether.

This flicker-eliminator technique can also be used with low-power RAM's in computer memory systems to prevent loss of stored data when a transient flicker occurs. The amount of "safety" time again depends on the value of *C2* and the current demands of the memory system. Therefore, the higher the value of *C2* and the lower the current demand, the longer the safety time. ◇



This circuit provides power to a clock chip to prevent flicker.



BUILD AN AUDIO COMPANDER

Provides greater dynamic range and reduces noise.

BY JOHN ROBERTS

PERHAPS the last frontier yet to be crossed by high-fidelity program sources is dynamic range. For example, the best consumer tape decks have a dynamic range of about 65 dB when used with premium tape formulas. Compare that to the 115-dB range of music produced by a symphonic orchestra at a live performance.

This project—a 2:1/1:2 compander—will allow you to record live music on your existing tape deck and later play it back without losing its original dynamic range. Other benefits of compansion are increased tape headroom during record and noise reduction during playback. These advantages can be realized whether the program material is being recorded live or transcribed from another format. The compander is easy to build and use, employs a new Signatics IC, and has a low parts count. A stereo compander is available in kit form as described in the Parts List.

Compansion involves compressing a signal's amplitude before it is committed to the recording medium, and then expanding it in a complementary fashion when it is recovered. This is typically accomplished by inserting a fixed-slope (2:1) compressor in the signal path before the tape deck's record preamp and a fixed-slope (1:2) expander at the output of the deck's playback preamp. The process is shown graphically in Fig. 1. Practicalities of electronic circuitry in preamps and power amplifiers limit their dynamic range to 100 to 120 dB. However, this approaches the dynamic range of live music and (comfortable) human hearing, easily attainable by a good tape deck working with a 2:1/1:2 compander.

The improvement in S/N becomes apparent when we look at a specific example. Let's assume that we have a tape deck with a noise floor of −45 dBm and that we want to record a piece of music with passages as low as −50 dBm. In the absence of any processing, the soft passages would disappear into the hiss. However, if we pass the signal through a 2:1 compressor before recording it, the minimum amplitude recorded is −25 dBm, a full 20 dB above the noise. On playback, passing the tape output through a 1:2 expander restores the −25-dBm signal to its original −50 dBm. Simultaneously, the noise drops by the same −25 dB to −70 dBm.

Improvements are also realized in the upward direction. That is, headroom is increased. A tape that previously saturated (causing distortion) at +10 dBm can now handle a +20-dBm signal at the compressor input. Although compansion increases S/N and headroom, it places more stringent requirements on the medium's frequency response and amplitude stability. Because the expander's gain depends on the level of the compressed signal applied to it, any amplitude errors will be magnified. In the case of a 2:1/1:2 compander, any frequency response errors or amplitude anomalies will be doubled.

A Compander IC. Signetics Corporation has recently developed an IC called the NE570. It is a dual-channel linear IC, and either section can be used independently of the other as a compressor or expander. A block diagram and pinout of the NE570 is shown in Fig.

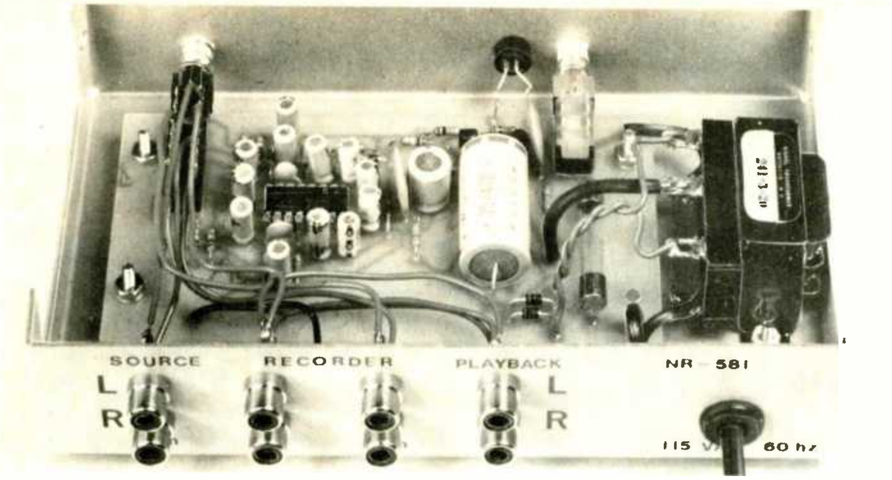


Photo shows prototype assembled on pc board and mounted in metal chassis.

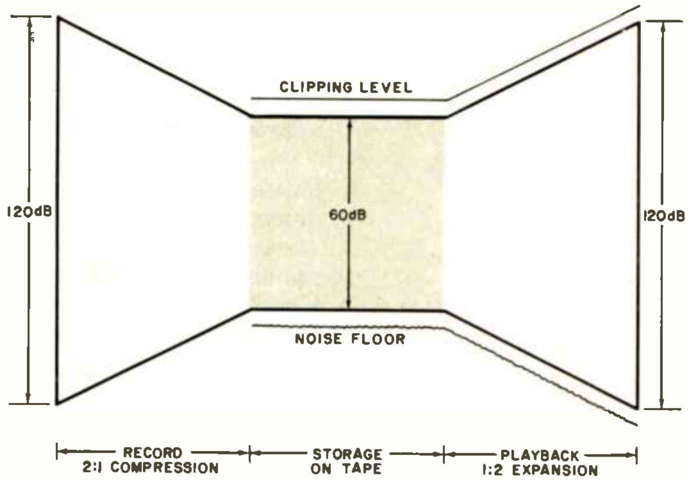


Fig. 1. Compression is used during recording, expansion on playback.

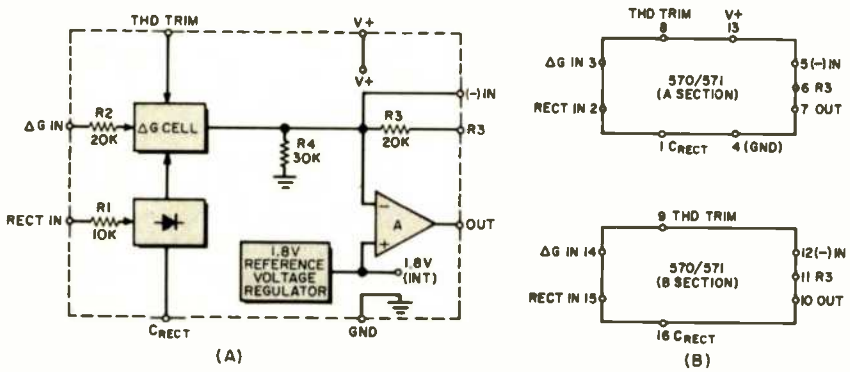


Fig. 2. Block diagram (A) and pinout (B) of the NE570 IC.

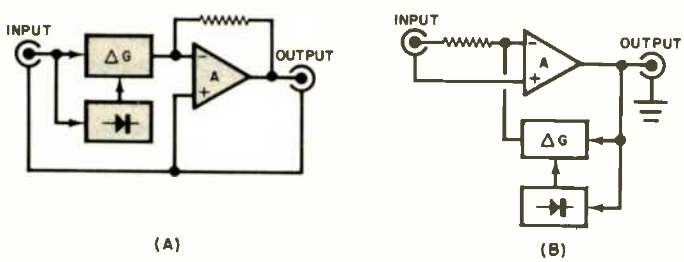


Fig. 3. Using the NE570 as an expander (A) and compressor (B).

2. Packaged in a 16-pin DIP, only the power supply and ground connections and an internal 1.8-volt bias regulator are shared by the two companders.

Each compander comprises a ΔG (variable gain) cell, a full-wave rectifier, and an output amplifier. The ΔG cell governs compander gain. Its control voltage is developed by rectifying an input signal. The output signal is generated by the op amp, which is driven by a scaled current supplied by the ΔG cell. Whether a section of the NE570 functions as a compressor or expander depends on how the basic blocks are interconnected. Typical specifications for the NE570 are in table on the next page.

A 1:2 dynamic range expander (Fig. 3A) is formed by placing the ΔG cell at the input of the op amp. Its control signal is generated by sampling the input signal, rectifying and filtering it. The fixed feedback impedance sets the overall gain at unity when the input signal is 0 dBm or 0.775 volt. As the input increases or decreases from this level, the gain increases or decreases proportionally. For example, if the input level increases by a factor of two (+ 6 dB), the output level is quadrupled (+12 dB). If the input decreases by one half (−6 dB), the output drops to one quarter (−12 dB) of its previous value.

Rearranging the blocks to form the network shown in Fig. 3B results in a 2:1 dynamic range compressor. Here, the ΔG cell is connected as a feedback impedance, and its control signal is derived from the op amp output. The fixed input network sets overall gain at unity for a 0-dBm signal. If the input signal level increases by a factor of four (+12 dB), the output amplitude is doubled (+6 dB). If the input amplitude is decreased by a factor of four (−12 dB), the output signal decreases by a factor of two (−6 dB).

About the Circuit. The schematic diagram of the compander is shown in Fig. 4. A conventional full-wave rectifier and RC filter supply the required operating voltages. Note that only one compander channel is shown. The components with the suffix "A" are for the channel A compander only. Integrated circuit pin numbers in parenthesis are the corresponding inputs and outputs of the channel B compander. For example, pin 1 is connected to *C4A*, and pin 16 should be connected to *C4B*.

Diodes *D3* and *D4*, *LED1*, transistors *Q1* and *Q2*, and their associated components form a level indicator. The LED glows when input signal peaks exceed 0 dBm. Switch *S2* interconnects the

TYPICAL SPECIFICATIONS
NE570 COMPANDER

Maximum input/output level	+12 dBm
Maximum output current	±20 mA
Unity gain level:	0 dBm ±1 dB
Tracking error:	±0.2 dB
Gain change with temperature (0° to 70° C):	±0.1 dB
Output slew rate	±0.5 V/μs
THD* (compressor or expander only)	0.3%
Expander noise output (measured with input shorted)	96 dBm A weighting
Frequency response,	
Compressor	20 to 20,000 Hz, +0, −1.5 dB at 0 dBm
Expander	20 to 20,000 Hz, +0.5, −1 dB at 0 dBm

*—Harmonic distortion is caused primarily by ΔG cell offsets and modulation of the cell by control voltage ripple. When the recorded signal is expanded by the same ΔG cell that compressed it, the distortion cancels out, leaving tape noise or tape distortion dominant. Note—a phase inversion in the record/playback path will affect the accuracy of this cancellation.

blocks of each section of the NE570 so that the IC functions as a compressor on record and an expander on playback. Pulsating dc from the full-wave rectifier is smoothed into the ΔG cell's control signal by capacitor *C4A*. Capacitors *C5A*, *C6A*, *C8A*, and *C9A* provide ac coupling between various parts of the compander circuit.

Construction. The compander is best assembled using a printed circuit board. Suitable etching and drilling and parts placement guides are shown in Fig. 5. When mounting electrolytic capacitors and semiconductors be sure to observe polarity and pin basing. An IC socket or Molex Soldercons are preferable to soldering the compander IC directly to the circuit board. Use the minimum amount

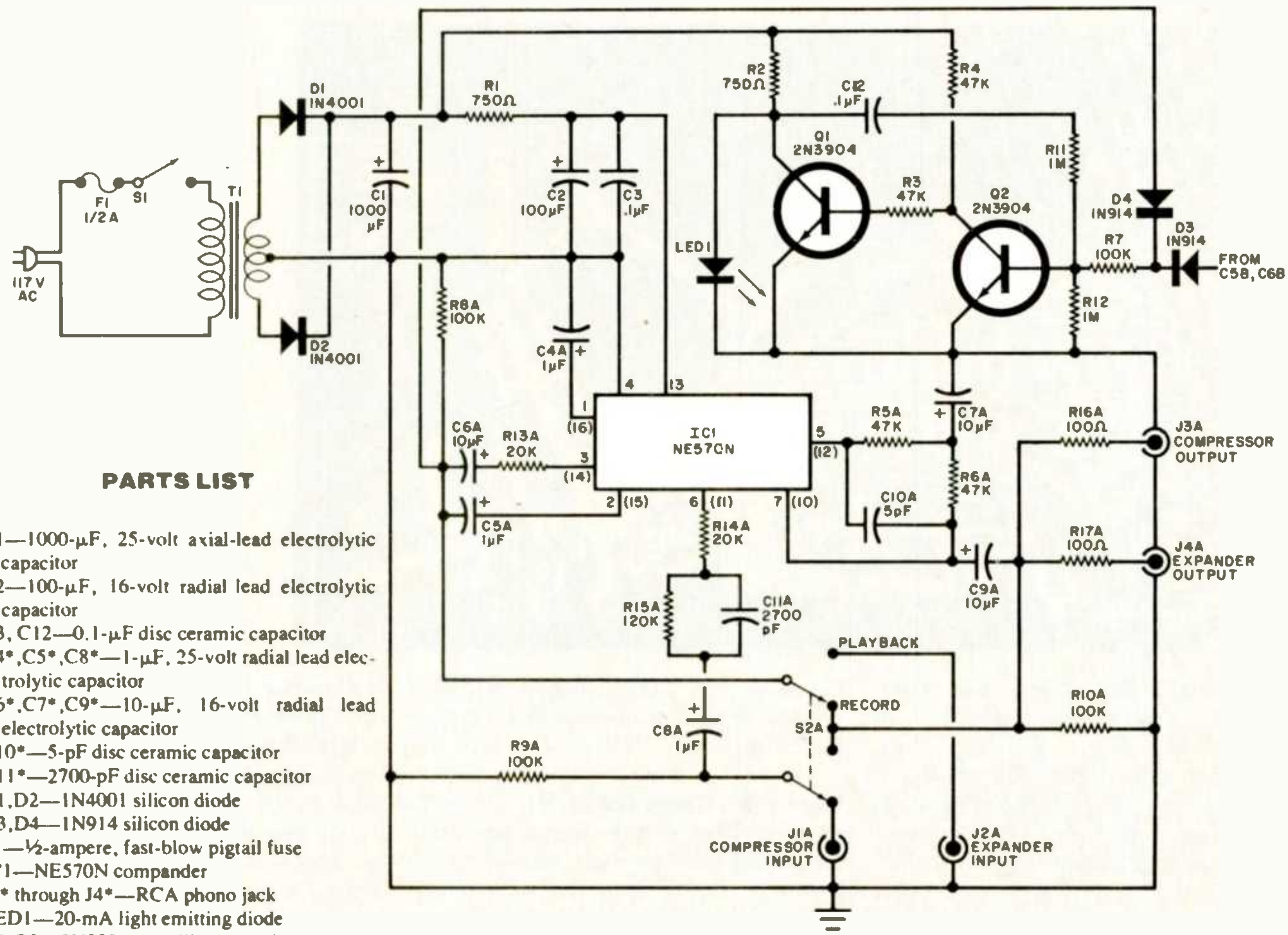
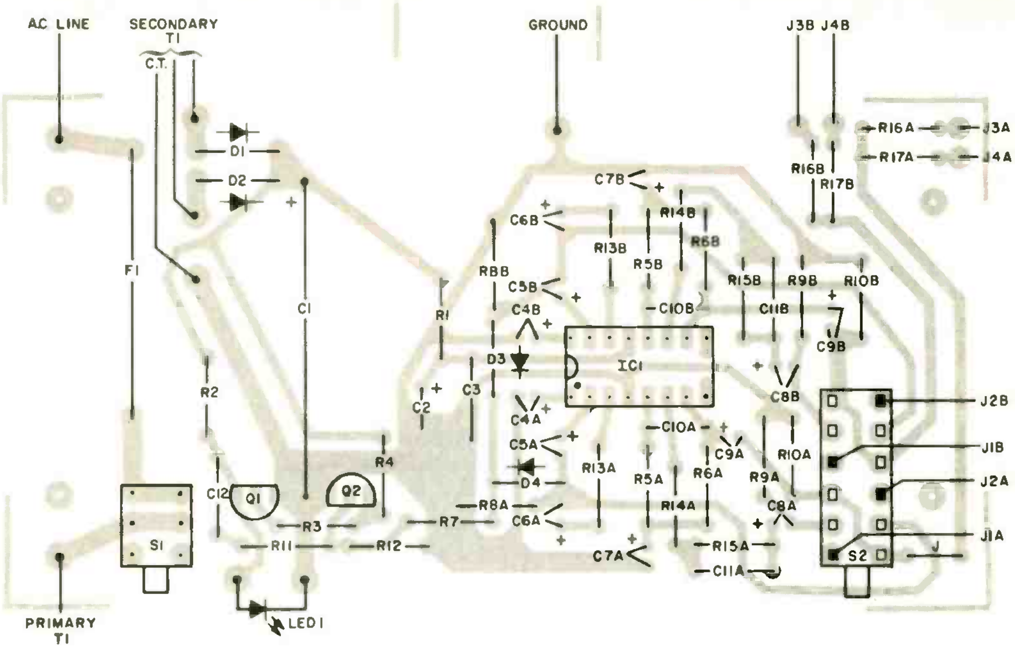


Fig. 4. In schematic of the compander, the "A" suffix is for one channel only. Duplicate components are needed for "B" channel.

PARTS LIST

C1—1000-μF, 25-volt axial-lead electrolytic capacitor
C2—100-μF, 16-volt radial lead electrolytic capacitor
C3, C12—0.1-μF disc ceramic capacitor
C4*,C5*,C8*—1-μF, 25-volt radial lead electrolytic capacitor
C6*,C7*,C9*—10-μF, 16-volt radial lead electrolytic capacitor
C10*—5-pF disc ceramic capacitor
C11*—2700-pF disc ceramic capacitor
D1,D2—1N4001 silicon diode
D3,D4—1N914 silicon diode
F1—½-ampere, fast-blow pigtail fuse
IC1—NE570N compander
J1* through J4*—RCA phono jack
LED1—20-mA light emitting diode
Q1,Q2—2N3904 npn silicon transistor
The following are ¼-watt, 5% tolerance carbon composition resistors:
R1,R2—750 ohms
R3,R4,R5*,R6*—47,000 ohms
R7,R8*,R9*,R10*—100,000 ohms
R11,R12—1 megohm
R13*,R14*—20,000 ohms
R15*—120,000 ohms
R16*,R17*—100 ohms
S1—SPST switch
S2—4PDT switch
T1—34.5-volt, 50-mA center-tapped transformer (Signal Transformer Co. No. 241-3-28 or equivalent)
Misc.—Line cord, strain relief, suitable enclosure, hookup wire, printed circuit board metal spacers, hardware, solder, etc.
Note—The following are available from Phoenix Systems, 375 Springhill Road, Monroe, CT 06468: complete kit of parts including case (No. P-518-S), $65.00; NE570N compander IC (No. P-518-C), $6.00; power transformer T1 (No. P-518-T), $5.00; etched and drilled pc board (No. P-518-B), $5.00; Connecticut residents please add 7½% sales tax; Canadians add $2.50 handling and shipping charges; $1.00 handling fee for orders under $10.00.
*—One component required for each compander channel.



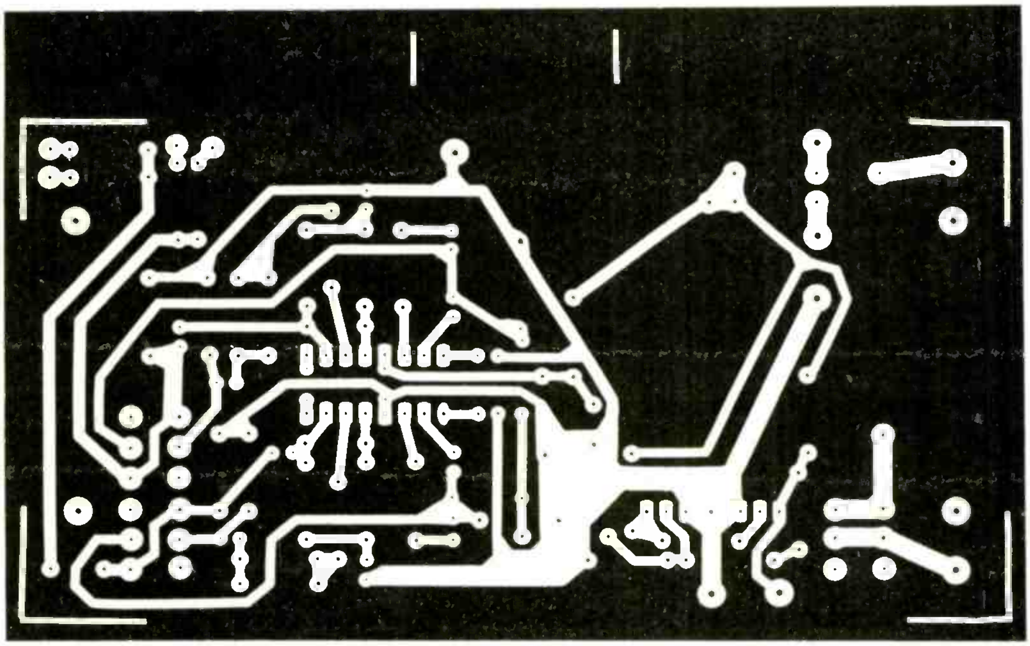


Fig. 5. Etching and drilling guide (left) and component placement (above) guides for the pc board.

of heat and solder consistent with the formation of good solder joints at each pc board pad.

If an alternate construction technique is used, care must be taken to keep all signal leads, especially those to switch *S2*, as short as possible. In any event, the circuit should be mounted in a metal enclosure that is connected to the audio system ground.

Using the Compander. Interconnect each channel of the compander and your system's tape deck and amplifier as shown in Fig. 6. Place *S2* in the RECORD position and adjust the deck's record preamp level controls for a reasonable record level. With the added dynamic range supplied by the compander, you can afford to trade a few dB of the deck's S/N for reduced distortion levels. (Some tape machines are set to run very close to saturation to get the highest S/N possible.) Indicator *LED1* is included not to alert you of clipping, but as an aid in setting record levels. The compander has at least 10 dB of headroom above the threshold at which the LED glows.

To play back a compressed tape, simply place *S2* in the PLAYBACK position and put the deck in its playback mode. You will then retrieve the recorded program with its original dynamic range. ◇

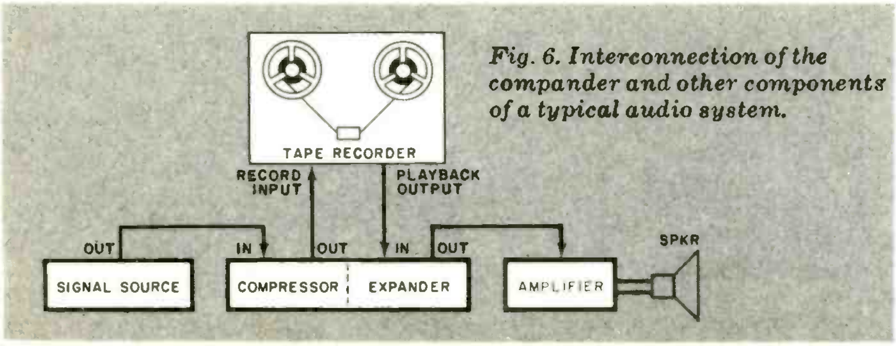


Fig. 6. Interconnection of the compander and other components of a typical audio system.

PHOTOELECTRIC SENSOR

DETECTS (AND COUNTS) ENTRANCES & EXITS

In/out detection system counts events (up and down) and can be used to control lights, appliances, etc.

BY DAVID MARKEGARD

MOST photoelectric entry detectors are unidirectional. They can detect when an individual enters a given area but not when he leaves. A more practical system, from both a security and a convenience point of view, would be able to detect motion in both directions. A store owner would then know whether or not all customers who entered his premises had left by the close of the day. In the home, such a system could be used to automatically turn on and off lights as you enter and leave a room.

The in/out detection system described here is a relatively simple and inexpensive approach that takes advantage of readily-available TTL IC's. It not only turns on the room lighting (or any other electrical device) when the first person enters the monitored area, it also keeps tabs on the number of people entering and leaving the area. The system turns off the electrical device only after the last person has passed the sensor while exiting the area.

The basic circuit is designed to count up and down a maximum of nine events. However, it can easily be modified to count 99, 999, etc., events simply by adding extra IC's and diodes. Additionally, the system can accommodate two or more sets of sensors should you have more than one doorway to monitor.

About the Circuit. In the circuit shown in Fig. 1, the UP and DOWN sections of the system operate in an identical manner, the only difference being in the direction of the count. Since operation is identical, we will discuss the sequence of events in only the UP section.

When an external light beam shines on *LDR1*, the resistance of this light-dependent resistor is a low 100 ohms (approximately). Consequently, the input to pin 13 of *IC1* is low, making the output of this inverter stage, at pin 12, high. Now, when the beam to *LDR1* is broken, the light-dependent resistor's characteristic resistance rapidly increases to several megohms, placing a relatively high positive voltage at the pin-13 input of *IC1* to generate a low output at pin 12. The steep edge of the rapidly falling voltage at pin 12 is differentiated by *C1*, *R2*, and *R3* to produce a sharp negative pulse whose width remains constant regardless of how long the light path to *LDR1* is broken.

Resistor *R2* also serves as a "pull-up" for the input of *IC2*, a timer integrated circuit that is connected as a one-shot multivibrator. When triggered, *IC2* generates a positive-going pulse at its pin-3 output. This pulse is then inverted by another inverter stage in *IC1*, after which it is passed to the "count-up" input (pin 5) of up/down counter *IC4*, registering a one-count increase. With each successive breaking of the beam to *LDR1*, the system registers another up-count (to a maximum 9 count, after which the system automatically resets to 0).

The same inverted signal that is applied to the pin-5 input of *IC4* is also applied to the reset input (pin 4) of *IC3*, another timer integrated circuit connected as a one-shot multivibrator. This inhibits the output of *IC3* and prevents any possibility of generating a false down-count in the system. Bear in mind that *LDR1* and *LDR2* in the finished project are mounted physically close to each other so that a common light beam can be used for both. This means that when an opaque body passes between the beam and *LDR1*, a discrete interval later it passes between *LDR2* and the beam. Hence, if *IC3* were not inhibited, the system would count up and almost immediately count down as the beam to first one and then the other LDR is broken. The system must, therefore, respond to the count generated by the first LDR to be activated—in this case, *LDR1*—for true bidirectional performance.

The four outputs from *IC4* are coupled through isolating diodes *D1* through *D4* and current-limiting resistor *R10* to the base of transistor *Q1*. The transistor is held in cutoff whenever all the outputs of *IC4* are low and conducts whenever any one or more outputs are high. When *Q1* is conducting, relay *K1* is energized and operates whatever external device is connected to its contacts.

As noted earlier, the basic system is configured for a maximum count of 9 in either direction. If you wish to increase the count range, you can add one or more 74192 up/down counter IC's to the basic circuit as shown in Fig. 2. Each added 74192 IC will then provide a one-decade increase in range. For example, two 74192's increase the maximum count to 99, three 74192's to 999, etc. When up/down counters are added, the "carry" and "borrow" pins (pins 12 and 13) of each preceding counter become the inputs to the next counter in line. Note also that all "clear" inputs (pin 14) of the counters must connect to CLEAR switch *S1*.

An adequate light source for the system can be obtained by using a low-voltage power transformer with an appropri-

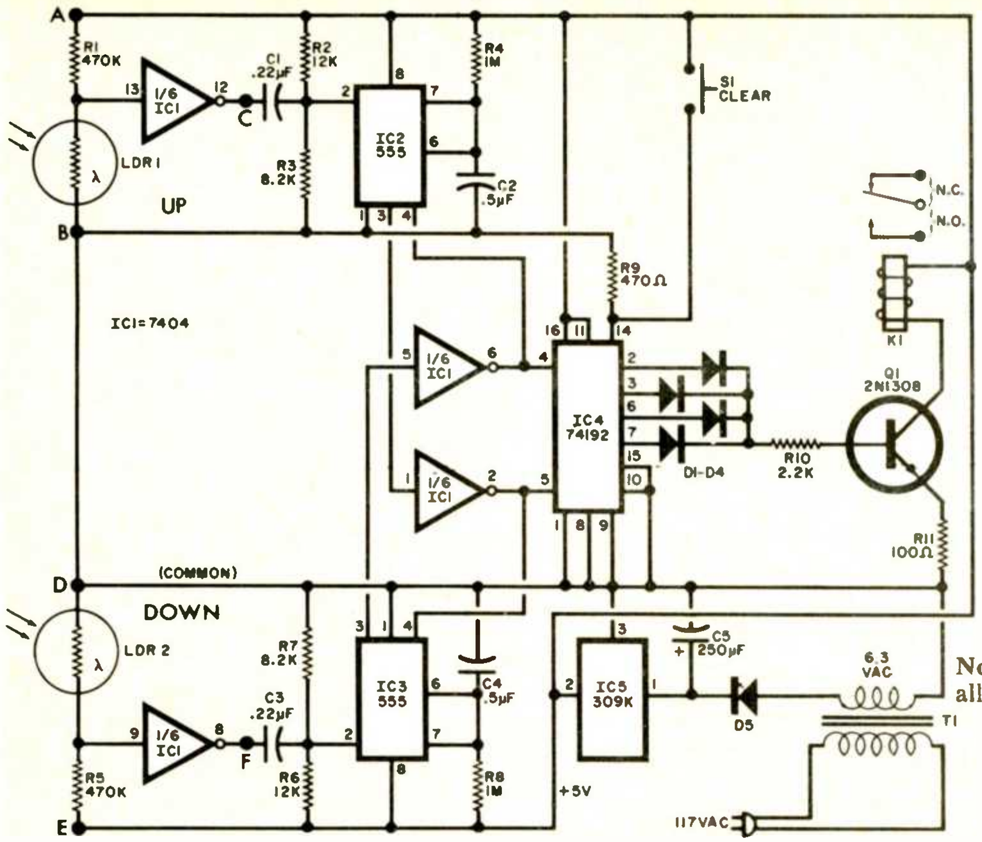


Fig. 1. Any sudden change in light on LDR1 causes an output pulse which is counted to drive relay K1. Two one-shots are cross-coupled so that only the first one activated is counted

Note: Substituting a 74193 for IC4 allows a count of 15 instead of 9.

PARTS LIST

C1, C3—0.22-µF capacitor
C2, C4—0.5-µF capacitor
C5—250-µF, 25-volt electrolytic capacitor
D1 through D5—1N4001 rectifier diode
IC1—7404 hex inverter IC
IC2, IC3—555 timer IC
IC4—74192 up/down counter IC
IC5—309 5-volt regulator IC
K1—3-volt, 25-mA relay (Calectro No. D1-965 or similar)
LDR1, LDR2—Light-dependent resistor with 1-megohm maximum, 100-ohm minimum resistance (Radio Shack No. 276-116 or similar)
Q1—2N1308 or similar transistor
The following resistors are ½-watt, 10%:
R1, R5—470,000 ohms
R2, R6—12,000 ohms
R3, R7—8200 ohms
R4, R8—1 megohm
R9—470 ohms
R10—2200 ohms
R11—100 ohms
S1—Spst momentary-action pushbutton switch
T1—12-volt, 300-mA power transformer
Misc.—IC and transistor sockets (optional); heat sink for IC5; perforated board; suitable box to house circuit; line cord; hookup wire; chassis-mounting ac receptacle; sheet of insulating plastic; materials for making light source (see text); rubber grommet; machine hardware; solder; etc.

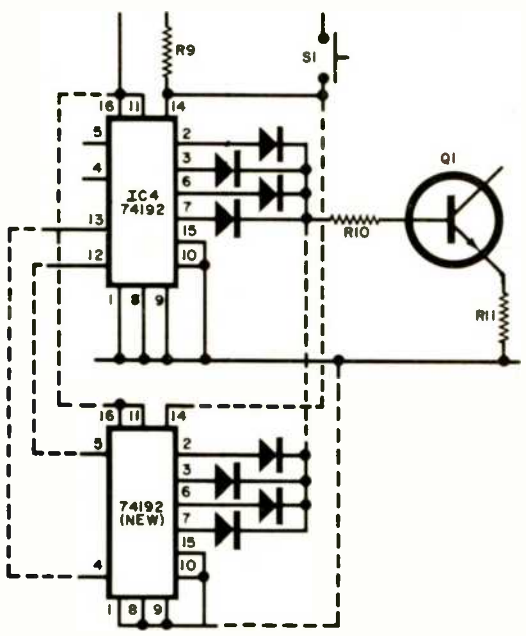


Fig. 2. Count can be increased by adding another up/down counter.

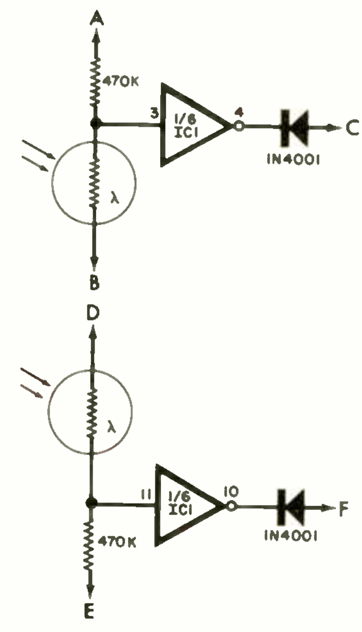


Fig. 3. Second pair of counting inputs can cover another entry.

ate panel lamp connected across its secondary winding. By wiring a 100-ohm potentiometer in series with one of the transformer's secondary leads and the lamp, you can vary the intensity of the beam to suit conditions. The lamp can be set into an ordinary flashlight reflector to focus the light into a narrow beam.

If it is necessary to cover a second doorway, the system will accommodate an extra pair of UP/DOWN counting inputs, connected as described in Fig. 3. This will use up the remaining two inverters in the 7404 hex inverter used for *IC1*. In the event that more than two doorways must be covered, extra UP/DOWN counting inputs can be used, provided that you add as many inverter pairs as there are LDR pairs.

Construction. There is nothing critical about circuit layout or lead routing. The entire circuit can be assembled on a 5" × 4" (12.7 × 11.4 cm) piece of perforated board, as shown in Fig. 4. It is

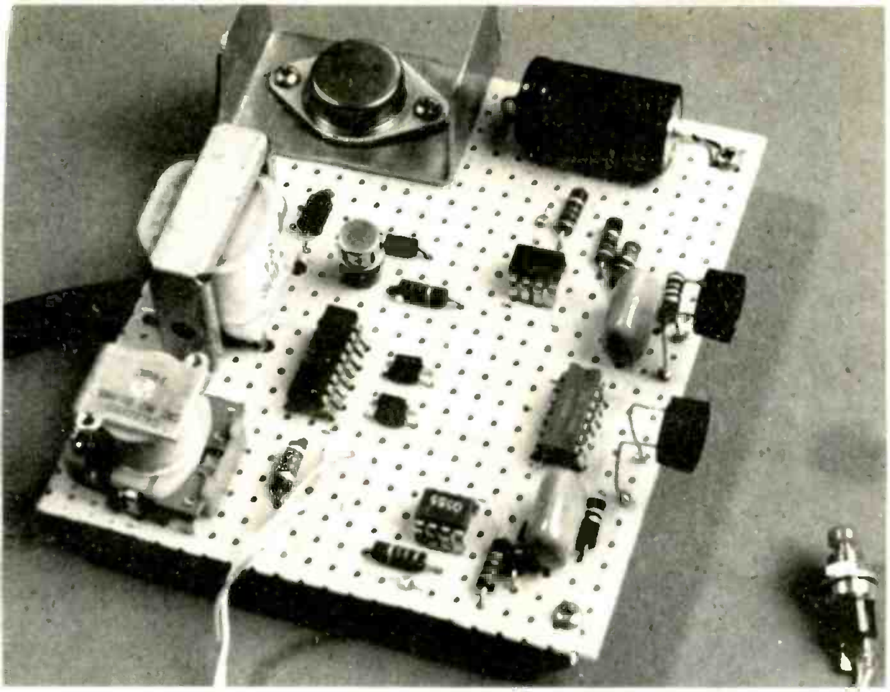


Fig. 4. The prototype of the photoelectric sensor was assembled entirely on perforated board. LDR's are on right side of board. CLEAR switch is connected by twisted leads.

advisable to use sockets for the IC's and transistor. Note also the need for a heat sink with *IC5*.

Light-dependent resistors *LDR1* and *LDR2* should be mounted about 1" (2.54 cm) apart so that a single light beam will suffice for both. If you are using extra UP/DOWN counting inputs, mount their LDR's on a small piece of perforated board. Cut holes in a small box to allow light-beam access to the LDR pair, mount the LDR board inside the box, and interconnect this assembly with the main board via twisted cable.

The box that houses the main circuit board should be large enough to accommodate the main circuit board, a chassis-mounting ac receptacle, and CLEAR pushbutton switch *S1*. Drill holes in the box as required to mount all components in place and to provide light-beam access to *LDR1* and *LDR2*. Mount *S1* and the receptacle in their respective holes. You can use ordinary hookup wire to interconnect *S1* with the circuit board, but it is advisable that you use a length of regular line cord to interconnect the relay contacts and the receptacle. Slip the free end of the line cord through a rubber-grommet-lined hole in the case and solder it to the appropriate points in the circuit. A sheet of insulating plastic should be placed between the box and the bottom of the board before the latter is finally bolted down. This will obviate the possibility of the live ac on the primary side of *T1* from shorting out against the metal box.

Testing the Circuit. Plug the system's line cord into a convenient ac receptacle and direct a beam of light onto *LDR1* and *LDR2*. The relay should immediately energize. Depressing the CLEAR button (*S1*) should cause the relay to immediately deenergize. Now, block the light beam by passing your hand in front of first *LDR1* and then *LDR2*. The relay should again energize. With the relay still energized, passing your hand in front of first *LDR2* and then *LDR1* should cause *K1* to drop out.

Pass your hand several times from *LDR1* to *LDR2*. The relay should immediately energize on the first pass and remain energized with each successive pass. Now pass your hand an equal number of times from *LDR2* to *LDR1*. The relay should remain energized for all but the last pass. On the last pass, the relay should deenergize. This procedure checks the up and down counting operation of the circuit.

The relay specified for *K1* in the Parts List can safely handle up to 3 amperes of current. If you wish to operate a device that requires a greater amount of current, you will have to substitute a low-voltage, low-current relay whose contacts can handle the current drain. Alternatively, you can use the specified relay to drive a higher-current relay. ◇

BY TONY CARISTI

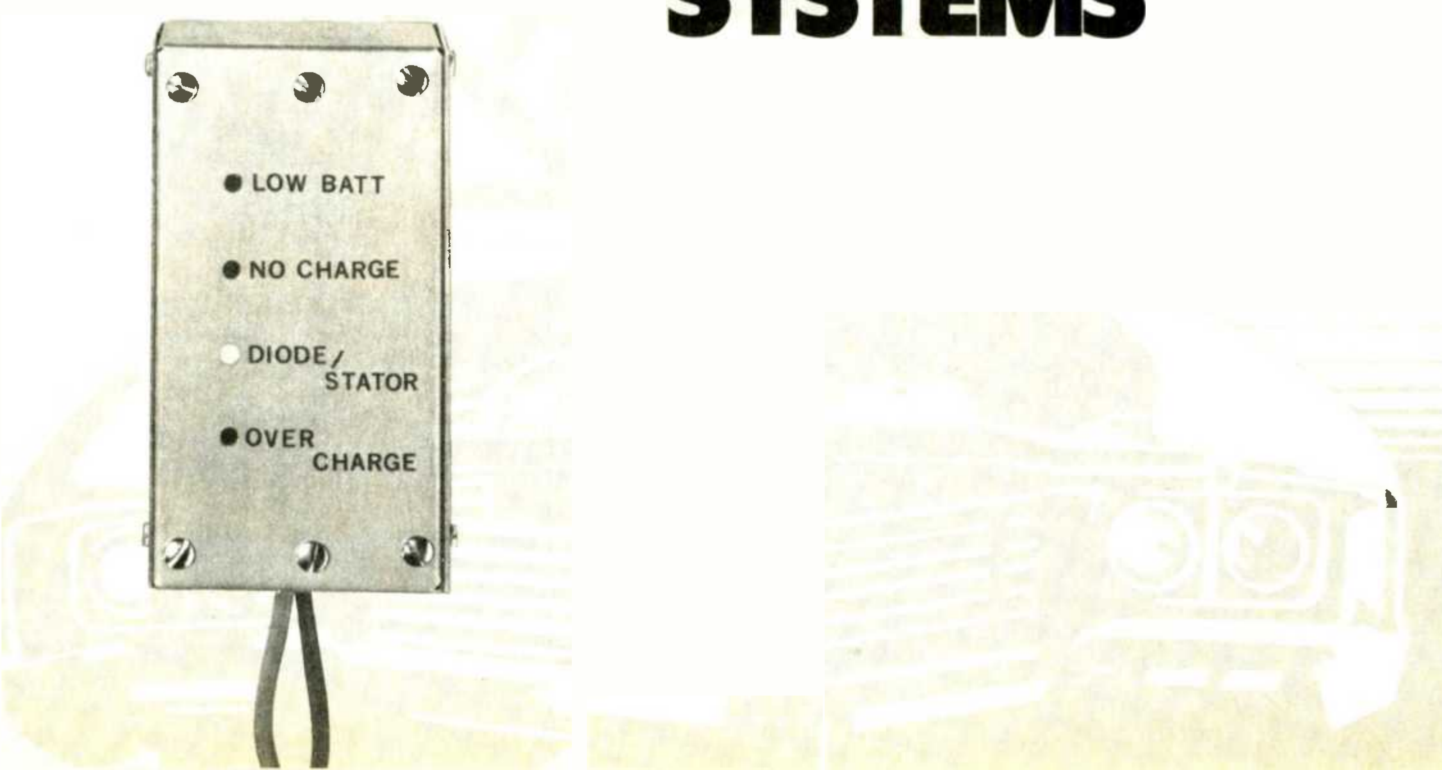
Electronic diagnostic instrument for locating and identifying problems in battery or charging systems

TROUBLE-SHOOTING ANALYZER FOR AUTOMOTIVE ELECTRIC SYSTEMS

THE AUTOMOTIVE industry has taken advantage of the latest techniques in modern electronics technology. As a result, many of the components in late-model automobiles have become more difficult to diagnose when trouble occurs. An example of this is in the automotive battery and charging system, where the old-style battery, dc generator, and electro-mechanical voltage regulator have given way to the sealed battery, alternator, and solid-state voltage regulator. These new components are superior to the ones they replaced, but they also require more sophisticated test procedures to analyze and isolate faults.

It seems only natural that electronics technology should provide the means to check these components. The automotive battery and charging system monitor described in this article provides such a check. It can be constructed at low cost, yet gives the accuracy and dependability suitable for a professional as well as an amateur. The monitor uses four LED's to provide an indication if a fault arises and also indicates possible sources of trouble. This feature will eliminate unnecessary replacement of properly operating components.

Circuit Operation. The analysis of an automotive battery and charging system can be accomplished by monitoring the battery voltage under several operational conditions, then comparing the measured value to a known standard.



PARTS LIST

- C1,C2 — 10-μF, 15-volt electrolytic
- D1 — 1N2069 or similar
- D2 — 1N4148 or similar
- IC1 — μA 78GU adjustable regulator (Fairchild)
- IC2 — LM339 quad comparator
- LED1 through LED4 — Red LED
- R1,R2,R4 — 1000-ohm, 1% resistor
- R3 — 1000-ohm potentiometer, pc mount
- R5 — 39,200-ohm, 1% resistor
- R6,R11,R14,R18 — 100,000-ohm, 1% resistor
- R7,R9,R15,R19 — 10,000-ohm, 10% resistor
- R8,R12,R16,R20 — 1000-ohm, 10% resistor
- R10 — 5900-ohm, 1% resistor
- R13 — 25,500-ohm, 1% resistor
- R17 — 19,600-ohm, 1% resistor
- Misc.—Suitable enclosure, interconnecting leads, optional spst switch, hardware, etc

Note: The following are available from: A. Caristi, 69 White Pond Rd., Waldwick, NJ 07463: etched and drilled pc board at $2.50; a set of 11 precision resistors at $3.00. Add 25c for postage.

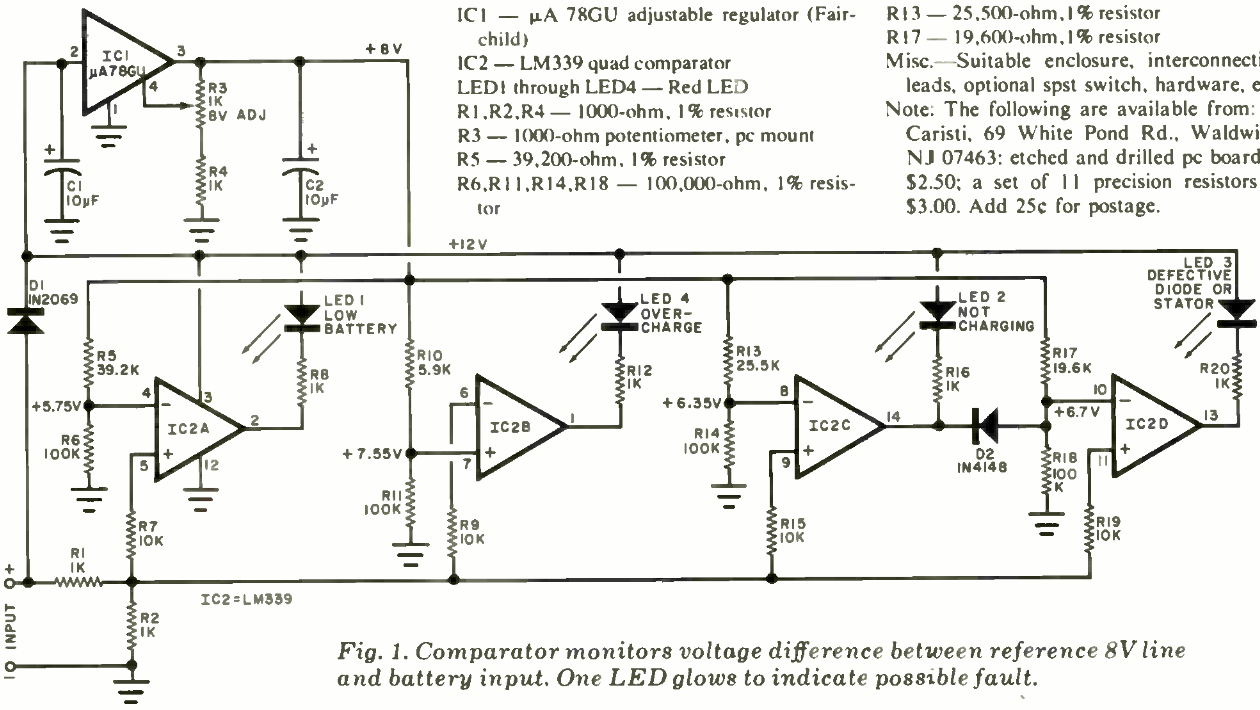


Fig. 1. Comparator monitors voltage difference between reference 8V line and battery input. One LED glows to indicate possible fault.

A properly operating battery and charging system will have a battery terminal voltage of about 12.6 volts when the engine has been turned off for some time, and between 13.5 and 15.0 volts when the engine is running and the battery is being charged.

If the battery voltage is below 11.5 volts with the engine not running, the battery is either in a very low state of charge or has a damaged cell. If the battery voltage is less than 12.7 volts with the engine running, the charging system is inoperative. If the voltage is less than 13.4 volts, then there is insufficient charging; if there is more than 15.1 volts across the battery terminals, overcharging is occuring.

The circuit shown in Fig. 1 constantly monitors the battery voltage, while LED displays indicate any improper electrical condition. The basic reference voltage for the monitor is formed by *IC1* which is an adjustable voltage regulator that is set to a precise 8-volt output.

This voltage reference is fed to four precision voltage-divider networks (*R5/R6*, *R10/R11*, *R13/R14* and *R17/R18*) that provide levels of 5.75, 7.55, 6.35 and 6.7 volts respectively, to individual sections of *IC2*. By feeding half the battery voltage to the noninverting input, the corresponding voltages then become 11.5, 15.1, 12.7 and 13.4 volts.

In *IC2A, C* and *D*, the precision reference voltage is fed to the inverting input (-) of the comparator, while half the system's battery voltage (via divider *R1, R2*) is coupled to the noninverting (+) input. As long as the voltage at the noninverting input is greater than the voltage applied to the inverting input, the output of the comparator is high. The associated LED is thus extinguished, indicating that the system is normal for that particular voltage level.

Should the battery voltage drop below the reference level, the comparator output drops to zero, causing the associated LED to indicate a malfunction.

Note that *IC2B* has its input terminals reversed; that is, the reference voltage is applied to the noninverting input while the battery voltage is applied to the inverting input. This causes its associated LED to glow if the battery voltage exceeds the reference level. This condition is also caused by a fault in the charging system. Diode *D2* is connected between the output of *IC2C* and the inverting input of *IC2D* to prevent *LED3* from lighting if *LED2* is glowing. This not only prevents the two indicators from lighting at the same time, but also provides a positive indication of a particular type of fault in the charging system.

Diode *D1* is connected in series with the positive input lead to protect the circuit against damage caused by an accidental reversal of the input leads.

Construction. The circuit can be assembled on a small pc board such as that shown in Fig. 2. Observe the polarities of the two diodes and two polarized capacitors. A 14-pin socket can be used for *IC2*. Pin 1 of *IC2* can be identified by a small dot or mark on the plastic case.

The four LEDs can be mounted where they are easily observed, and then connected to their respective pads on the pc board. Each LED must be clearly identified as to indicated fault.

A long length of insulated wire can be connected between the monitor positive input and the battery positive terminal The monitor's negative input may be connected to a chassis ground.

Test and Adjustment. A 0- to 16-volt dc power supply and an accurate dc voltmeter are used to test the monitor.

Observing the correct polarity, connect the two monitor input leads to the power supply, and set the power supply for a 12-volt output.

Connect the voltmeter positive lead to *IC1* pin 3, and the negative lead to ground. Adjust *R3* until the voltmeter indicates precisely 8 volts.

Connect the voltmeter across the

power supply, then reduce the supply down to 11 volts. Both *LED1* (Low Battery) and *LED2* (Not Charging) indicators should be glowing. The other two LED's should be dark.

Slowly increase the power supply voltage until *LED1* is extinguished. This should occur between 11.4 and 11.6 volts. As the power supply output is increased, note that *LED2* should extinguish between 12.6 and 12.8 volts, and *LED3* (Defective Diode or Stator) should light when *LED2* goes out.

As the power supply output is further increased, *LED3* should go out when the voltage is between 13.3 and 13.5 volts. *LED4* (Overcharge) should glow when the supply voltage exceeds 15.1 volts. *Do not raise the power supply output above 16 volts!*

If any of the LEDs do not operate properly, check the 8-volt line, then make sure that the correct precision resistors are used at the proper comparator inputs.

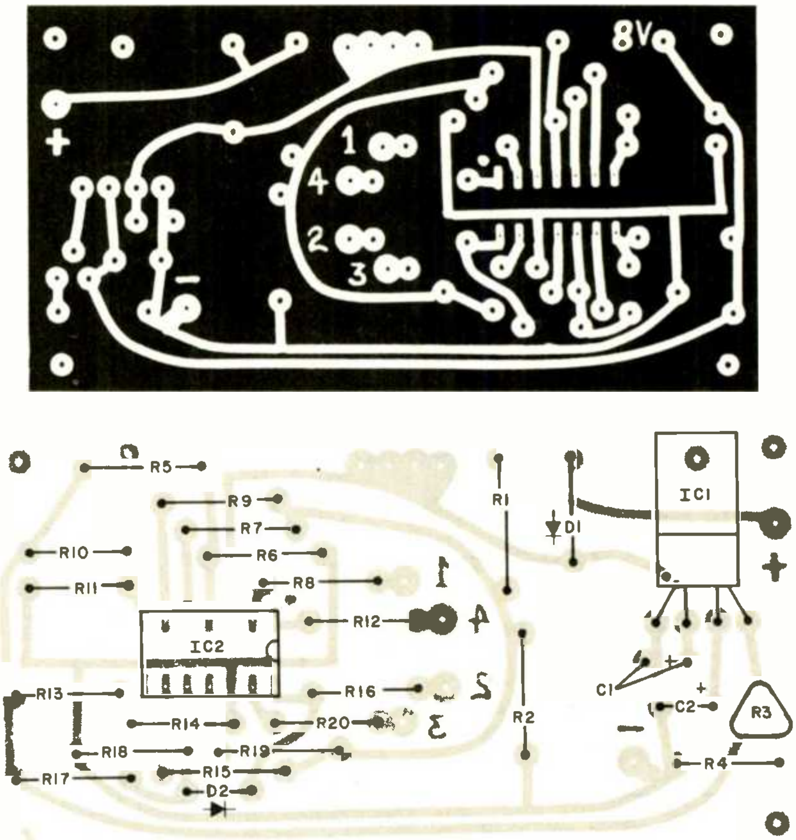


Fig. 2. Actual size etching and drilling guide for pc board is at top; component layout diagram below.

Using the Monitor. The following steps should be performed in sequence when checking an automotive battery and charging system. Connect the monitor to the vehicle's battery terminals, being sure to observe correct polarity for each terminal.

An spst switch can be connected between the monitor positive input lead and the battery so that the monitor can be disabled when not in use. Make sure that the alternator drive belt has the proper tension.

Before the engine is started, the Not Charging (*LED2*) or Defective Diode or Stator (*LED3*) will be lighted since the battery is not yet being charged. If the Low Battery (*LED1*) glows, the battery voltage is less than 11.5 volts. This can be caused by a state of deep discharge or a faulty cell. If this LED is glowing, investigate the battery before proceeding.

When the engine is started and everything is normal, all the LEDs should be dark. If there is an electrical malfunction, then one of the LEDs will glow.

If the Not Charging LED glows, the terminal voltage of the battery is less than 12.7. Thus, the alternator is not delivering any current to the battery. This can be caused by an open regulator circuit or open alternator field.

If the Defective Diode or Stator LED glows, the terminal voltage of the battery is less than 13.4 volts. This can be caused by a shorted diode or stator in the alternator, or an improperly adjusted regulator.

If the Overcharging LED glows, the terminal voltage of the battery is greater than 15.1 volts. This can be caused by a shorted or misadjusted regulator.

If no LEDs glow with the engine running, load the alternator by turning on the headlights' high beams, the air conditioner, the high-speed blower, the high-speed windshield wipers and the radio. Then moderately race the engine. All LEDs should be extinguished.

If the Defective Diode or Stator LED is now lighted, but was extinguished with no load on the alternator, the most likely cause of the problem is an open diode in the alternator.

This low-cost, easy-to-use automotive instrument can save the builder many dollars of repair costs, making it a worthwhile investment in parts and labor. ◇

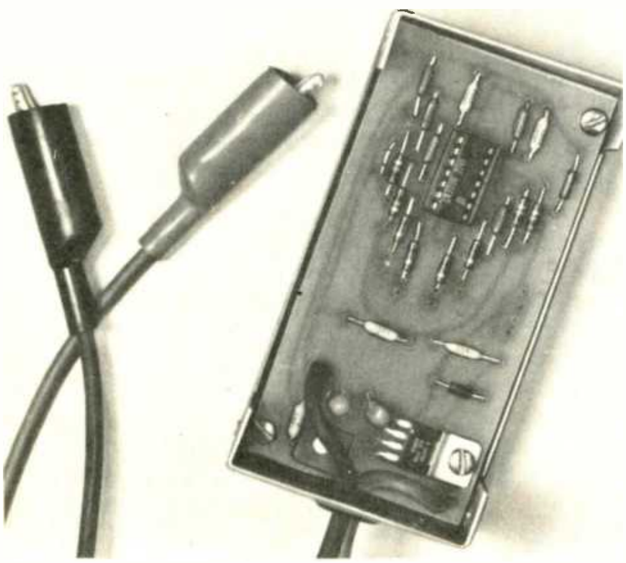


Photo of interior of author's prototype shows components mounted on printed circuit board and connections to enclosure.

BY JOSEPH CARR

HOW TO DESIGN & BUILD POWER SUPPLIES

PART 1

Basics of transformers, rectifiers, filters, voltage regulators and protection circuits.

WHEN YOU design or build projects, particularly large-scale designs in which many transistors and/or IC's are used, most of the effort goes into creating the final circuit and the printed circuit board. All too often, the power supply is just an afterthought. This is unfortunate because even a well-designed and assembled project may operate borderline if the power supply is not delivering the correct voltage at the required current. This problem is compounded when the supply must deliver large amounts of current, as in multi-IC digital circuits, especially microcomputers. Hence, the power supply deserves special attention, since it is often critical to the success of an electronic project.

In this first of a two-part article we will discuss power supply basics, some design concepts, etc. By the end of Part II, you should be able to design low-voltage, high-current power supplies that can perform as required for just about any project.

Transformers. The transformer is generally a voltage converter. It reduces the standard 117-volt ac power line potential to the lower voltages required in solid-state electronics. Most discrete circuits operate with potentials in the 1.5-to-28-volt range; linear IC systems operate in the range from ±4.5 to ±18 volts; CMOS circuits require between 4 and 18 volts; and TTL requires the use of a tightly regulated 5-volt supply line.

Because a transformer is very efficient, stepping the line potential down in the secondary winding increases the current available for any given voltage level. The primary VA (volts times amperes) rating is very nearly equal to the VA rating of the secondary. Simply stated, $E_{pri} \times I_{pri} = E_{sec} \times I_{sec}$, where E_{pri} is the potential in the primary winding (117 volts ac); I_{pri} is the primary current; E_{sec} is the voltage in the secondary; and I_{sec} is the secondary current.

Rectifier. The rectifier converts the alternating current from the transformer's secondary into pulsating direct current (dc). The simplest of rectifiers is the half-wave circuit shown in Fig. 1.

All rectifiers operate on the same principles, whether they are solid-state or vacuum-tube types. They conduct current in only one direction. When an ac sine wave is applied to the input of this circuit, current passes through the rectifier only when its anode is more positive than its cathode, as in Fig. 1A. On the other half of the ac cycle, the rectifier

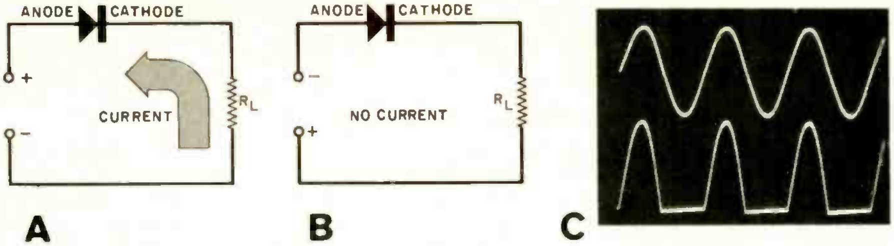


Fig. 1. Forward-biased diode (A) conducts current while reverse-biased diode (B) does not. In (C), upper trace is ac input, lower trace is pulsating dc across load.

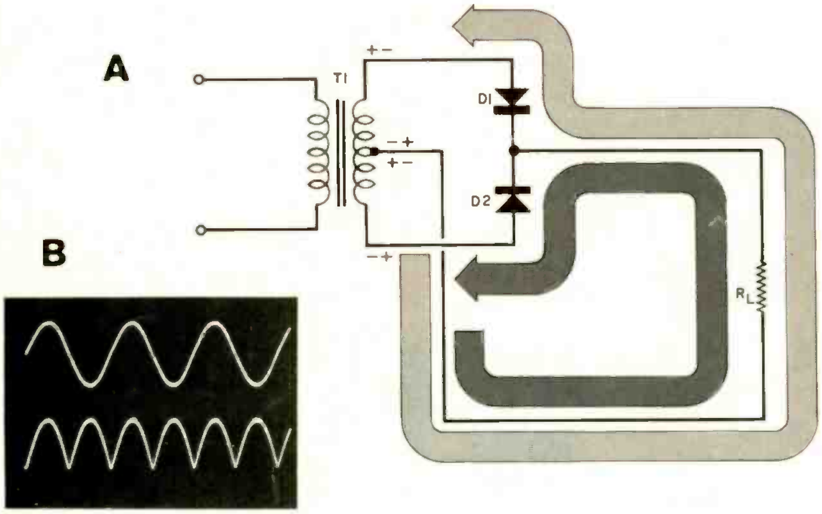


Fig. 2. At (A) is fullwave rectifier. Ac in primary of T1 is upper trace in (B), pulsating dc is at bottom.

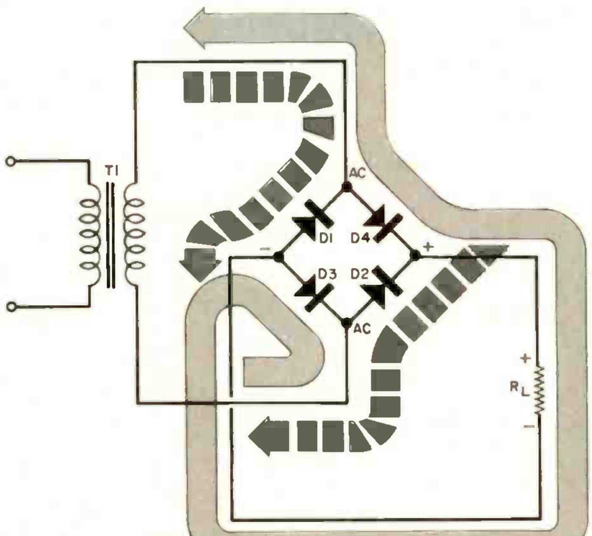


Fig. 3. A full-wave bridge rectifier. Broken lines show current flow during each half of the ac input cycle.

is reverse-biased (Fig. 1B), thus preventing the flow of current through the external load, R_L.

The waveforms associated with the half-wave rectifier are shown in Fig. 1C. The top waveform is that of the ac sine wave applied to the input, while the bottom waveform shows the rectified pulsating dc output across R_L. Note that the pulsating dc output exists only when the input waveform is in its positive alternation. Because half of the input waveform is not used, the half-wave rectifier is very wasteful of electrical energy. And half-wave rectification presents difficulties in filtering the output to pure dc with no ripple component.

The half-wave rectifier has an average output potential of approximately 0.45 times the applied rms potential and its ripple amounts to 120%. To add to the problems of this design, the transformer used must have a primary VA rating 40% greater than is required if full-wave rectification were used.

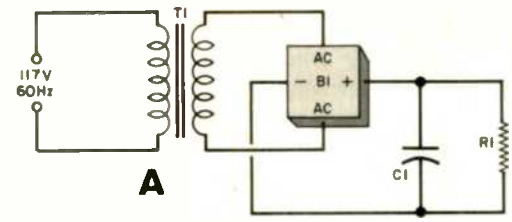
A basic full-wave rectifier using a center-tapped transformer is illustrated in Fig. 2A. At any given ac peak, one end of the transformer's secondary is positive, while the other end is negative. The center tap is at a potential that is half that across the entire secondary. Therefore, if the center tap is used as the common reference, equal and opposite polarity potentials will be found at either end of the secondary with respect to the center tap.

Let us consider the case when the top of the secondary is more positive than the bottom. Current flows from the common center tap through R_L and forward-biased rectifier *D1* (whose anode is more positive than its cathode) and then back to the transformer. During this period, *D2* is reverse-biased due to the negative potential at its anode so that no current can flow through it.

On the alternate half-cycle, *D1* becomes reverse-biased and *D2* conducts. Current then flows from the center tap through R_L and forward-biased *D2* and back to the secondary of the transformer. Note that, in both cases, the current flows through the load in the same direction. This produces the "double-humped" waveform across R_L shown in the lower trace of Fig. 2B. In essence, the negative-going portion of the applied ac sine wave has been "folded up" to produce the double-frequency waveform shown in the figure.

The bridge circuit shown in Fig. 3 is another type of full-wave rectifier. It employs a diode "ring" (*D1* through *D4*) for rectification. The secondary of the transformer is not center tapped; the diode ring provides the negative (sometimes ground) reference point. The two "corners" of the bridge labelled "+" and "−" and go to the positive and negative sides of the filter capacitor.

Since the bridge rectifier circuit em-



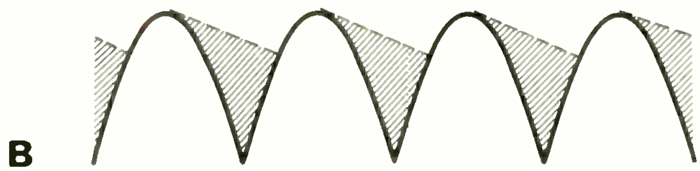


Fig. 4. Simple power supply with capacitance filter (A). Waveforms in (B) show how capacitor fills in between humps to smooth ripple.

ploys the entire secondary potential, it produces an output potential (pulsating dc) of twice that of the ordinary full-wave rectifier using the same transformer. There is one catch, however. The bridge rectifier supply delivers only half the current of the full-wave rectifier for a given primary VA rating. There are occasions when it is possible to exceed this and draw nearly the full rated current from the transformer's secondary without causing damage, but this is not dependable in all cases.

The average dc output potential in an unfiltered full-wave supply is approximately 0.9 times the applied rms potential, or about twice the voltage obtained with the half-wave rectifier. Both types of full-wave rectifiers have an output ripple component of about 48% and, thus, need filtering to produce the dc required by the electronic circuits. Also, the ripple frequency in the full-wave rectifier circuit is 120 Hz, which is twice the frequency of the line power.

Filters. The filter smoothes out the pulsating dc output from the rectifier to create the nearly pure dc required by the electronic circuitry load.

The half-wave rectifier produces one dc pulse for each ac cycle (Fig. 1C), while the full-wave supply produces two dc pulses per cycle (Fig. 2B). These waveforms illustrate the difference in ripple frequency—60 Hz for the half-wave and 120-Hz for the full-wave rectifiers—and implies that the higher frequency of the full-wave rectifier's output is easier to filter.

The usual high-value capacitor found in power supplies is shown in Fig. 4A. In this circuit, the bridge rectifier is shown in block form, since it is most often a bridge-rectifier assembly rather than a set of four discrete rectifier diodes. Filter capacitor *C1* is connected directly across the rectifier.

The value of *C1* is critical to the performance of the power supply. It should be no less than 1000 µF per ampere of output current; many authorities claim that 2000 µF per ampere should be the minimum. In any event, it is good practice to use not less than 1000 µF in projects that draw 1 ampere or less current. A typical 5-volt, 4-ampere dc power supply for a small digital computer would require not less than 8000 microfarads for a good filtering.

The waveform shown in Fig. 4B illustrates how the filter capacitor reduces the level of the pulsations in the rectified output waveform. Capacitor *C1* charges up as long as the pulsating dc applied to it is rising. Once the peak potential has been reached and the rectified waveform begins to drop toward zero, the capacitor dumps its charge to fill up the spaces (shaded area in Fig. 4B) between the pulses. Obviously, the greater the charge dumped, the smoother will be the top of the output waveform from the filter. The five waveforms shown in Fig. 5 were obtained from a low-voltage, 5-ampere supply using different amounts of filter capacitance. The circuit employed was that shown in Fig. 4, using a transformer rated at 13 volts and 10 amperes.

The Fig. 5A waveform shows the unfiltered output across the load resistor. The base line represents the 0-volt level, while the peak of the pulsating dc waveform is just short of 19 volts. The result of connecting a 150-µF capacitor across the load is shown in Fig. 5B. Note that the ripple has been reduced and has taken the shape of the filtered output shown in Fig. 4B. A dc voltmeter connected across the load indicated approximately 13 volts when there was

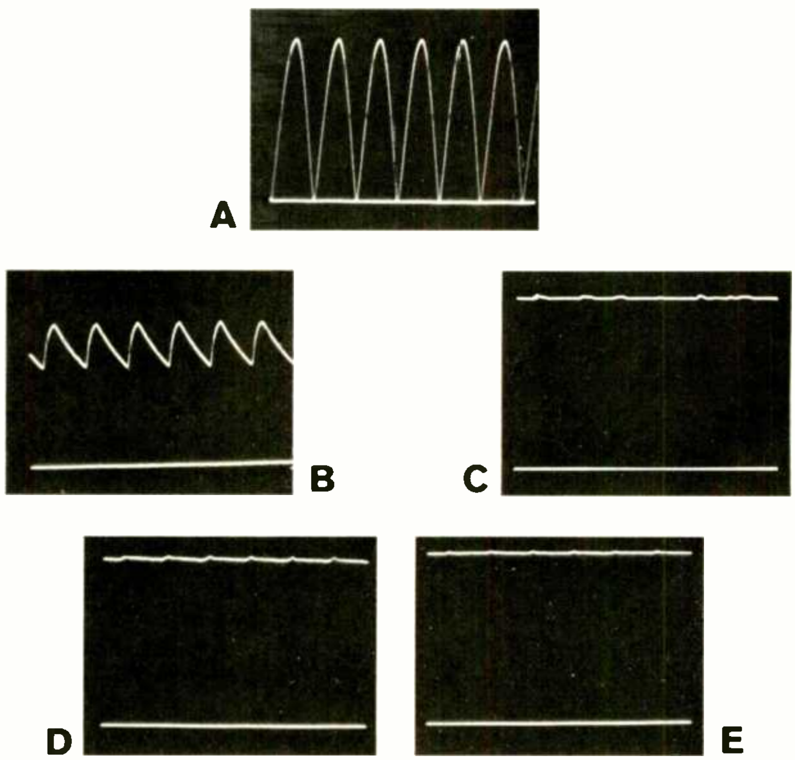


Fig. 5. How capacitors smooth waveform. Lower trace is zero volts. (A) is full-wave dc without filter; (B) has 150-µF capacitor; (C) 2000 µF; (D) 5000 µF; (E) 18,000 µF.

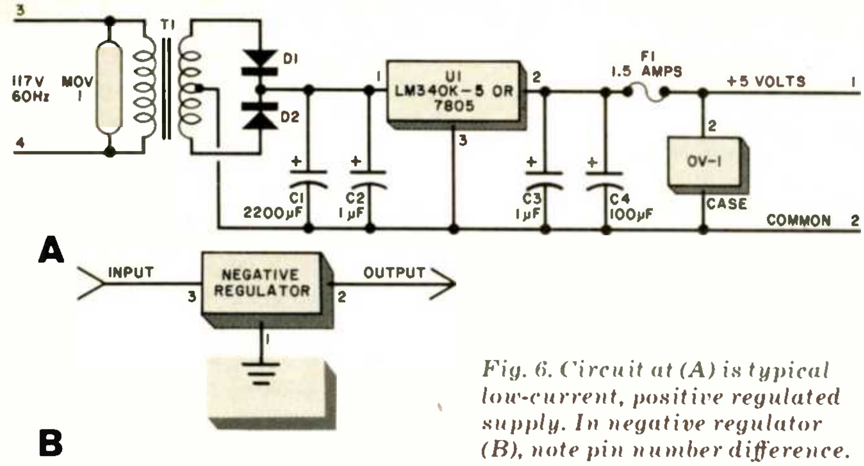


Fig. 6. Circuit at (A) is typical low-current, positive regulated supply. In negative regulator (B), note pin number difference.

no filtering. With the 150-μF capacitor installed, it indicated 16.8 volts.

Connecting a 2000-μF capacitor across the load produced the Fig. 5C waveform. The ripple is substantially reduced and the average dc potential has risen to about 18 volts. The situation is even better in Fig. 5D, where the capacitance is 5000 μF. The ripple has lessened to the point of almost disappearing. The dc potential has risen only an additional 0.7 volt, to 18.7 volts. In the Fig. 5E waveform, an 18,000-μF capacitor is across the load, which results in less ripple but no increase in the dc output potential. Bear in mind that this is for a 4-ampere power supply in which the formula capacitance should have been 8000 microfarads.

Voltage Regulators. Circuits that maintain their output potential constant over a wide range of load variations are termed "voltage regulators." Most computers and all TTL circuits fare better on such regulated power supplies.

Voltage regulators for low-current levels are reasonably simple. Up to 5 amperes, conventional low-cost three-terminal IC regulators can be used. The circuit of a power supply in which a three-terminal regulator is used is shown in Fig. 6A.

Several different but essentially similar families of three-terminal IC regulators exist. Probably the most familiar is the LM309 series, the LM309H being a 100-mA device in a TO-5 package and the LM309K a 1-ampere device in a TO-3 case.

There is also the LM340 series in which the output voltage is indicated by a number suffix added to the basic series number. For example, the LM340-5 is a 5-volt regulator, while the LM340-12 is a 12-volt device. These devices are available with outputs up to 24 volts. They come in two package styles—the K package for 1-ampere and the T package for 750-mA capacity.

The LM320 devices are essentially the same as the LM340 devices, except that they are designed for negative output voltages. Note that the pinouts for the negative regulator shown in Fig. 6B are different than for the positive regulator. Failure to observe this fact can result in catastrophic damage when the power supply is turned on.

Another well-known regulator family is the 7800 (positive) and 7900 (negative) series. The output potential is given by the last two digits in the type number (7805 for +5 volts and 7812 for +12 volts output, for example).

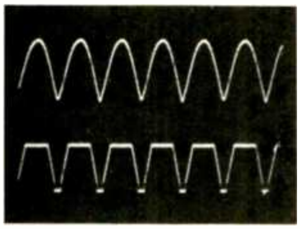


Fig. 7. Bottom waveform shows how a regulator "limits" peaks on rectified pulsating dc.

As shown in Fig. 6A, all three-terminal regulators should have noise bypass capacitors (*C2* and *C3*) across their input and output terminals. Various manufacturers specify different values for these bypass capacitors, the most common being between 0.33 and 2 μF. These noise filters should be wired as close to the terminals of the regulator as possible. If you use the lower value, the capacitor should be of ceramic disc construction. If the higher value is used, select a tantalum capacitor.

Capacitor *C4* is optional but desirable, especially where output current demands are very dynamic. The capacitance usually specified is on the order of 100 μF per ampere, or about a tenth of the value of the main filter capacitor. This added capacitor is not specifically used for filtering but to provide a "hedge" against output voltage droop under transient load conditions.

It is necessary to use a filter capacitor before a regulator; and Fig. 7 reveals why. The upper trace is the pulsating dc obtained from the rectifier, while the lower trace is the output of the regulator when filter capacitor *C1* is disconnected from the circuit. The unfiltered but regulated output waveform rises in each cycle until it reaches the cutoff point of the regulator, at which point it clips. Now, examine the waveform shown in Fig. 8. Although these waveforms appear to be similar to those shown in Fig. 5, they are different. In Fig. 5, the lower trace was used to indicate the 0-volt base line, while in Fig. 8 they illustrate the input (upper) and output (lower) of a three-terminal regulator. These traces are ac-coupled to the oscilloscope so that the dc component is suppressed and to permit the 5000-μF ripple component to be shown on a larger scale. The preregulation waveform of the upper trace was taken using a 0.2-volt/cm sensitivity in the scope's vertical channel, while a 0.01-volt/cm sensitivity was used for the lower trace. Even at 20 times sensitivity, no apparent ripple appears in the output waveform on the scope.

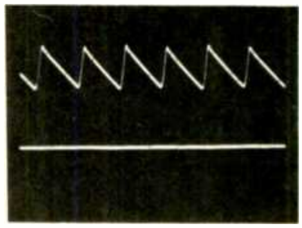


Fig. 8. Waveform at top is before regulator. Lower trace shows how ripple is eliminated.

Overvoltage Protection. Unfortunately, there are occasions when "something happens" in the regulator that permits the output voltage to rise above the required level. This potentially disastrous situation can be averted with an overvoltage protection circuit like that shown in Fig. 9. This circuit is called a

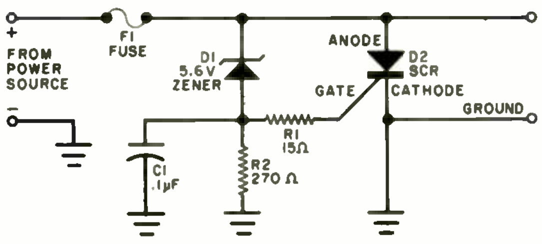


Fig. 9. Crowbar overvoltage protection circuit "fires" when 5-volt line exceeds breakdown voltage of zener diode.

"crowbar" because it operates by shorting the output to ground in the same manner as a conducting metal crowbar would if it were actually connected across the supply.

Normally, the supply potential (in this case +5 volts) is too low to allow zener diode *D1* to conduct. Consequently, the SCR presents a high impedance that makes it "invisible" to the dc line. When the potential on the supply line exceeds 5.6 volts, *D1* conducts and generates a voltage across *R2*. This voltage is then applied, via *R1*, to the gate of the SCR, which triggers on. When this occurs, the short circuit that results causes fuse *F1* to blow and shut down power. Although this circuit appears to be a little crude, it is extremely effective and can prevent damage to an expensive system connected to the power supply.

If you decide to use the crowbar protection circuit shown in Fig. 9, select an SCR that can handle about twice the current normally delivered by the power supply. Also, use a conventional fast-blow fuse for *F1*.

Some of the circuits we will discuss in Part II employ commercially available overvoltage protection devices, such as the OV-1 shown in Fig. 6A.

Current Limiting. This feature is usually found in supplies that employ more sophisticated voltage regulator circuits than those described above. Essentially, a small-value resistor is connected in series with the output lead of the regulator and the current drawn by the load generates a small voltage drop across this resistor. This voltage is applied to a comparator/amplifier that shuts down the power supply if excess current is drawn by the load.

Coming Up. In Part II of this article, we will discuss further design criteria. We will also present four construction projects: a +8-volt, 15-ampere power supply for Altair (S-100) bus microcomputers +5-volt, 4-ampere power supply; ±12-volt, 1-ampere power supply; and a sophisticated 5-volt, 10-ampere power supply with overvoltage protection and current-limiting shutdown. ◇

PART 2

Some typical, easy-to-build circuit applications.

IN THIS section, we will give some advice on the overall circuit design of such supplies and discuss several construction projects.

Some Basics. The transformer for the supply should have a current rating higher than that required by the electronics system it is powering. Many transformers will operate excessively hot when operated at their rated current, so a safety margin is a good investment. Also, keep in mind that, when a transformer is specified, a bridge-rectified supply can safely draw only one-half of the transformer's rated secondary current without exceeding the transformer's primary VA (volts times amperes) rating. In some cases the secondary rating can be exceeded, but it is risky.

A filtered power supply will produce an output that is close to the peak voltage appearing across the transformer secondary, but the transformer ratings are likely to be in terms of the rms voltage, which is defined as 0.707E *peak*. The voltage that appears across the filter capacitor will be between 0.9E *peak* and the peak voltage, rather than the rms voltage.

You may conclude then, that the output voltage will approach 1.4 times the rms voltage rating of the transformer secondary. For a typical power supply designed for the Altair (S-100) bus systems, a 6.3-volt transformer with a bridge rectifier will generate the "nominal 8 volts" required with this approach. Alternatively, a 12.6-volt transformer and a conventional full-wave rectifier will also do the trick. These secondary voltages are popular in high-power transmitter filament supplies, so it is relatively easy to locate both 6.3- and 12.6-volt transformers having high current ratings at electronics surplus dealers, hamfests, and auctions. One transformer manufacturer, Triad, makes three transformers that power-supply builders should investigate. The F-22A is rated at 6.3 volts at 20 amperes; the F-24U at 6.3/7.5 volts at eight amperes; and the F-28U at 6.3/7.5 volts at 25 amperes. The last two models offer the advantage of a tapped primary so that either 6.3 or 7.5 volts appear across the secondary, depending on which tap is used.

Do not skimp on the rectifiers. Always use individual rectifier diodes, or molded bridges with current ratings greater than the expected requirements. If possible, a rectifier having a rating 150 to 200% higher than the current predicted should be used.

The peak inverse voltage (piv) or peak reverse voltage (prv) as it is sometimes called, is critical. The peak voltage is defined as 1.4 times the rms rating of the transformer, and this is the voltage to which the filter capacitor charges.

Once during each power-line cycle, the capacitor voltage is in series with the entire rectifier voltage, so the reverse voltage applied to the diodes is two times 1.4 rms, or 2.8 times rms. This means that the piv rating of the rectifier diode should be 2.8 times the applied rms voltage. Some designers prefer three times rms for safety.

When using a 6.3-volt transformer, there are few problems since the lowest piv rating for most rectifier diodes is about 25 volts. However, consider the case when a 12.6-, 18-, or 24-volt transformer is used. In the first case, a 50-volt piv diode rating is adequate; but in the second, this rating is marginal; and in the third case, it is unsatisfactory. In the latter two cases, a 100-volt piv rectifier is required.

When using regulator transistors, or three-terminal IC voltage regulators, be generous with the size of the heatsink. This is not an area in which to skimp, since getting rid of heat is essential to the long life and reliability of the circuit. Keep in mind that a shorted series-pass transistor in a power supply can easily destroy the circuit it is powering. Even if an associated overvoltage protection circuit works properly, it might not operate fast enough to protect certain types of semiconductors.

8-Volt, 15-Ampere Supply. The Altair bus, also called the S-100 bus by non-Altair manufacturers, uses the concept of distributed voltage regulation. In this case, the computer mainframe power supply generates a well-filtered but unregulated +8 volts. Each circuit board that "plugs" into the bus has its own 5-volt regulator, usually of the 1-A type.

Most three-terminal regulators require an input voltage 2 to 3 volts higher than the output voltage rating. If a lower voltage is applied to the input, the voltage will drop and become unregulated.

The power dissipated by a regulator is $(V_{in} - V_{out})I$. Thus, with an 8-volt input, a regulator that delivers 5 volts at its full rated current of 1 ampere will dissipate 3 watts of heat. The S-100 bus 8-volt supply then, is proper for the +5 volts required by TTL devices. Up to +35 volts could be used as the input for such regulators, but that is unwise since it would increase the dissipation of the regulator to the danger point.

The circuit for an 8-volt, 15-ampere power supply is shown in Fig. 1. Transformer *T1* is rated at 6.3 volts and 25 amperes. The rectifier is a 25-ampere bridge stack mounted on its own heatsink. The filter capacitor (*C1*) is rated at 80,000 µF and reduces the ripple to a few millivolts. Resistor *R1* across the output is required for static testing since the unloaded voltage approaches 14 volts—common with high-current, low-voltage transformer supplies. Resistor *R1* solves the problem at a cost of only 80 mA of current drain. Transformer *T1*, like many high-current units, comes with "solderless" terminals. These did work loose during construction so a good lesson to learn is: always solder solderless connections. This becomes imperative in high-current supplies.

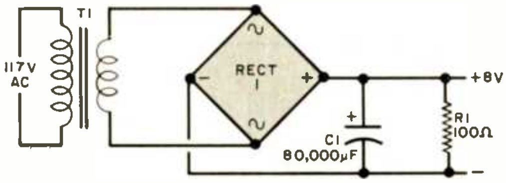
Since the major expense in this (and other) high-current power supplies is the transformer, it may pay to shop judiciously through various surplus stores that handle electronic equipment, in search of transformers in the 15-to-30-ampere range.

5-Volt, 4-Ampere Regulated Supply. Most digital circuits use many TTL logic units, and therefore require a power source of 5 volts at a couple of amperes. The circuit shown in Fig. 2 can deliver well-regulated 5 volts at 4 amperes (or 5 amperes with regulator and rectifier heatsinking).

The circuit is powered from a transformer rated at 6.3/7.5 volts at 8 amperes. Capacitor *C1*, the main filter, was selected according to the rule requiring 2000-µF/output ampere. This produced a value of 8000 µF. Tantalum capacitors are used for *C2* and *C3* to reduce the susceptibility of the voltage regulator to noise pulses on the power line. For best results, these capacitors must be mounted as close as possible to the input and output connectors of the regulator. Capacitor *C4* is used to improve the transient response of the regulator under highly dynamic current changes while the digital circuit is operating (see Part 1). The value of *C4* is determined by the 100-µF/output ampere rule, so it should be 400 µF but the next highest standard value of 500 µF is used.

The voltage regulator is a three-terminal device that can deliver 5 volts at 5 amperes. In this case, it was a Lambda type LAS-1905 (Lambda Electronics, 515 Broad Hollow Road, Melville, NY 11746). Although the single-unit price is about $14, this one device does save the several components that would be required to use a low-current regulator drive with a series-pass transistor. It is also much simpler to use.

As usual, provide a suitable heatsink



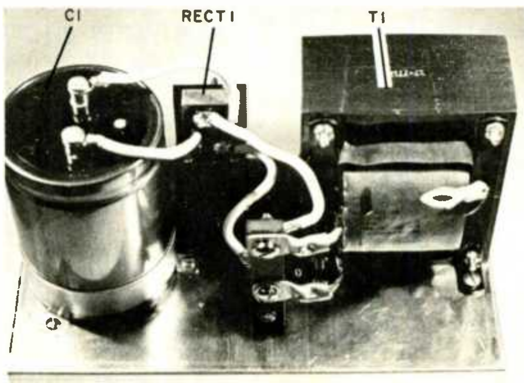


Fig. 1. Basic 8-volt, 15-ampere dc source. Note heavy wiring between elements.

PARTS LIST

C1 — 80,000-µF, 15-V electrolytic
R1 — 100-ohm, 2-W resistor
RECT1 — 25-A bridge rectifier (GE GEBR-425 or similar)
T1 — 6.3-V, 25-A transformer (Triad F-28U or similar)

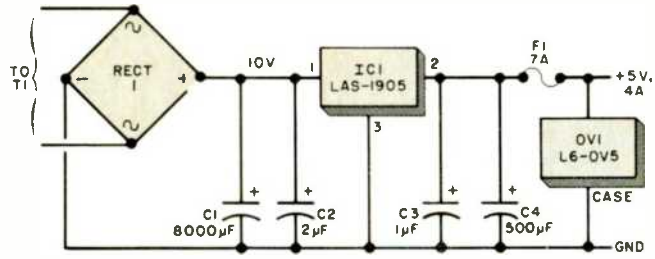
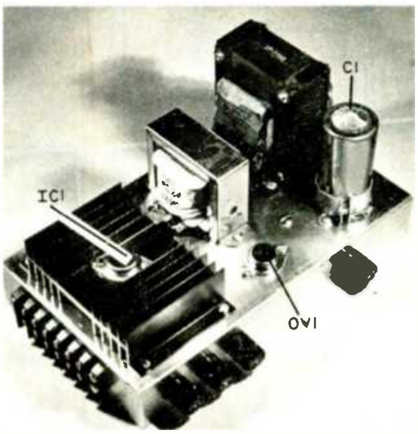


Fig. 2. Five-volt, 4-A dc supply with overvoltage protection. Extra transformer is for an unregulated supply whose components are not shown.

PARTS LIST

C1 — 8000-µF, 25-V electrolytic
C2 — 2-µF, 25-V tantalum capacitor
C3 — 1-µF, 25-V tantalum capacitor
C4 — 500-µF, 15-V electrolytic
F1 — 7-A, fast-blow fuse and holder
IC1 — 5-V, 5-A regulator (Lambda LAS-1905 or similar)
OV1 — 5-V overvoltage protector (Lambda L6-OV5 or similar)
RECT1 — 25-A bridge rectifier (GE GEBR-425 or similar)



for the voltage regulator so that it will run cool at its full rated current.

The over-voltage protection (*OV1* in Fig. 2), is an SCR crowbar type (see Part 1) also manufactured by Lambda. This TO-3 size protection circuit will fire the crowbar at 6.6 volts. Note that pin 1 of this circuit is left floating for proper operation in this application.

12-Volt, 1-Ampere Supply. Many circuits, including those using linear IC's (especially op amps), and S-100 boards require dual-polarity supplies at reasonable current. The circuit shown in Fig. 3 features two supplies driven from a common transformer, delivering +12 and −12 volts to ground at 1 ampere each.

The transformer is a 25-volt center-tapped unit rated (at the least) at 2 amperes. However, if you intend to operate close to the 1-ampere output, the transformer may either run hot, or not deliver the current, so a unit rated at 3 amperes is preferable.

The circuit uses a full-wave bridge stack (with a minimum rating of 1 ampere), but it is actually wired as two half-wave rectifiers since the transformer center tap is the common ground. The negative terminal of the bridge feeds the negative supply, while the positive terminal feeds the positive supply.

The filter-regulator portions of the supply are the same as those previously used, except that independent regulators are used for each side. Again, heatsinks should be provided for the regulators to keep them operating cool. Note also that over-voltage protection modules (OV1 and OV2) are used. Because these modules are available in only one polarity, the negative supply protector is used "upside down," making it necessary to "float" the case above ground.

5-Volt, 10-Ampere Supply. The circuit shown in Fig. 4 delivers regulated 5 volts at 10 amperes. The transformer delivers 6.3 volts at 20 amperes. The series-pass transistor (*Q1*) and the IC voltage regulator are conventional HEP types. Two versions of the IC regulator are available, but only the one having the "R" suffix is suitable for this application. (The low-power version, having the "G" suffix, may work properly heat-sinked). Capacitors *C2*, *C3*, and *C4* should be mounted as close as possible to the appropriate pins of the IC voltage regulator.

Pin 5 of the regulator is the output-sense terminal and is used to provide means for remotely sensing the level of the output voltage. Ordinarily, this is not a requirement for low-current supplies, but at high output currents (several amperes), the voltage drop in the wiring between the power supply and load can reduce the voltage at the load below the

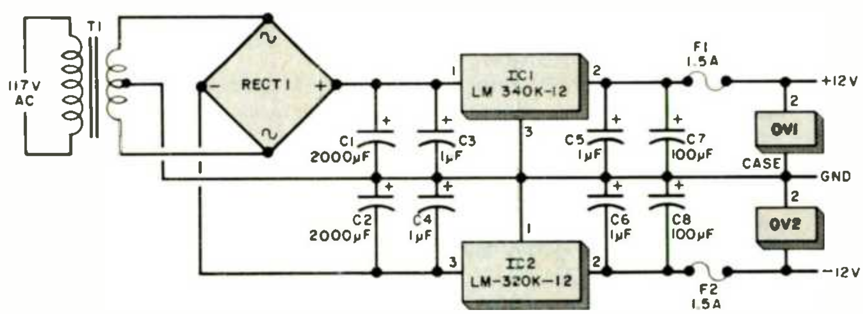
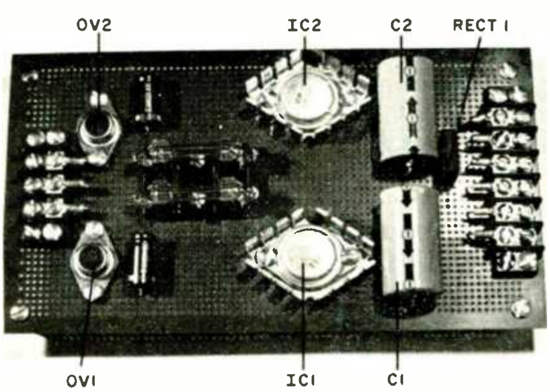
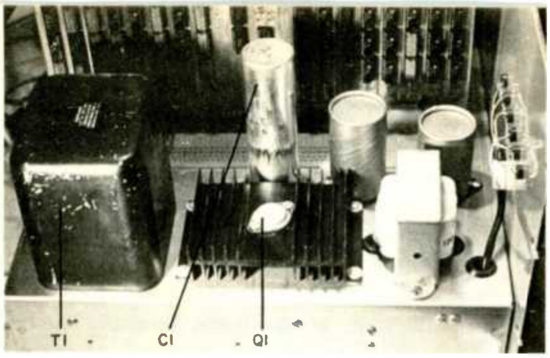


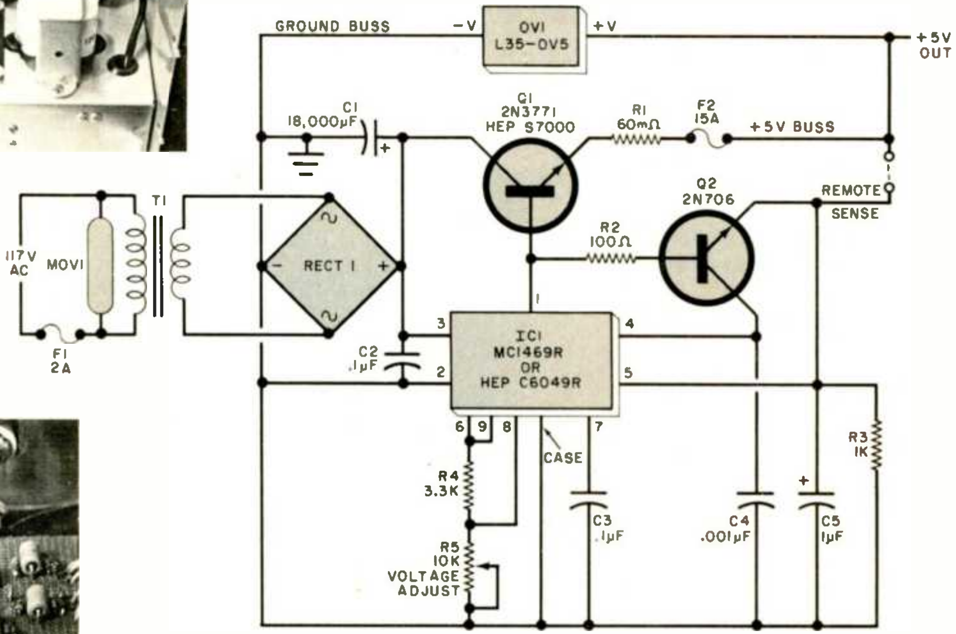
Fig. 3. Dual-polarity 12-volt supply includes optional overvoltage protection. Note use of barrier strips for power-supply connections.



PARTS LIST

C1,C2—2000-µF, 25-V electrolytic
C3 through C6—1-µF, 25-V electrolytic
C7,C8—100-µF, 15-V tantalum capacitor
F1,F2—1.5-A 3AG fuse and holder
IC1—+12-V regulator (LM340K-12 or similar)
IC2—12-V regulator (LM320K-12 or similar)
OV1,OV2—12-V overvoltage protector (Lambda L2-OV12 or similar)
RECT1—1-A, 200-piv bridge rectifier
T1—25.2-V, 2.8-A transformer (Triad F-56X or similar)





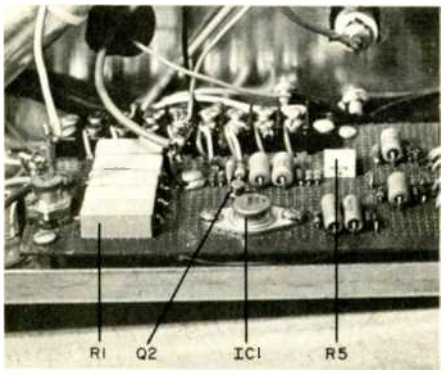


Fig. 4. Typical regulated supply for 5 V at 10 A. Circuit includes a line over-voltage protector and current limiting regulator. Photo at top shows top of chassis. Underneath view is directly above.

PARTS LIST

C1 — 18,000-μF, 15-V electrolytic
C2,C3 — 0.1-μF, 50-V capacitor
C4 — 0.001-μF, 50-V capacitor
C5 — 1-μF, 25-V tantalum capacitor
F1 — 2-A, 3AG fuse and holder
F2—15-A fuse and holder
IC1—MC1469R or HEP C6049R (Motorola) voltage regulator
MOV1— Metal oxide transient suppressor (GE)
OV1 — 5-V overvoltage protector (Lambda L35-OV5 or similar)
Q1—2N3771 or HEP S7000 (Motorola)
Q2 — 2N706 or similar
R1 — 60-milliohm (use five 0.33-ohm in parallel)
R2 — 100-ohm, ½-W resistor
R3 — 1000-ohm, ½-W resistor
R4 — 3300-ohm, ½-W resistor
R5 — 10,000-ohm trimmer potentiometer
RECT1 — 25-A bridge rectifier (GE GEBR-425 or similar)
T1 — 6.3-V 25-A transformer (Triad F-28U or similar)

4.75 volts specified for proper operation of TTL devices. In one test, 18 inches of #12 wire dropped the 5-volt output of the power supply to 4.5 volts at the TTL devices, resulting in erratic operation.

The remote sense line, connected to pin 5, is connected to the same point on the TTL board as the +5-volt line from the main power source. Thus, the IC regulator is using the actual board voltage as the reference, and can compensate the power supply for the unwanted voltage drop. This means that the actual output of the power supply is higher than the nominal 5 volts. If wiring voltage drop is not a problem in your system, then simply connect the remote sense line (pin 5) to the actual output (+5 volts) of the supply. Again, overvoltage protection is provided by an SCR crowbar circuit.

A new element can be added to this circuit—a line over-voltage protector across the transformer primary. This particular device (called a MOV) is made by General Electric and "looks" like a pair of back-to-back zeners, having a 117-125-volt ac voltage rating. It clips any high-voltage line transients that exceed the rated voltage. These line transients, which can reach many hundreds of volts, can be generated by local lightning storms or by inductive loads being switched somewhere on the common power line. Keep in mind that semiconductor junctions fail catastrophically when excessive voltage is applied, in many cases for only a very brief time. The use of the MOV does not guarantee that you will have complete protection, but it does give the system a chance to survive such a transient.

Another feature of the supply shown in Fig. 4 is current limiting with auto shut-down. Pin 4 of the IC regulator (the current limiting input) is controlled by transistor *Q2*. The base bias of *Q2* is controlled by the voltage drop across the small-valued series resistor *R1*. (This resistor, a 60-milliohm unit, can be fabricated from five 0.33-ohm resistors connected in parallel.) The value of this resistor for other current-limiting levels can be calculated (approximately) from *R1* = 0.6/I.

At an output current of 8.5 amperes, series-pass transistor *Q1* started to operate uncomfortably hot after about 20 minutes. A 50-cfm "muffin" fan was used to blow air across the heatsink of *Q1* and solved this problem. Without the fan, the case temperature of *Q1* is too hot to touch after one hour of operation, but with the fan, it remains comfortably warm. The cooler operation of the voltage regulator will prolong its life. ◇

BY MARTIN SMAHA

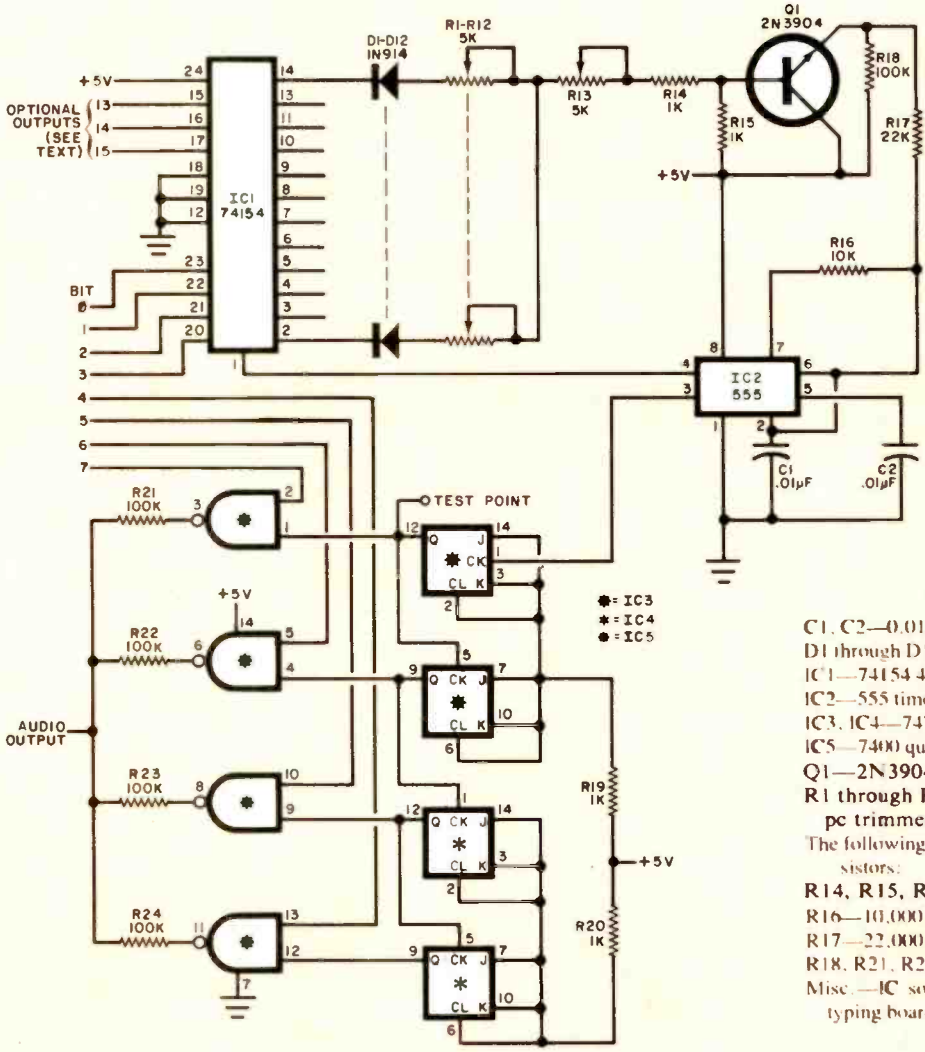
Build a COMPUTER MUSIC BOX PERIPHERAL

Low-cost, 12-tone, 4-octave music generator also produces test signals.

JUDGING from the many commercial plug-ins available, computer-generated music appears to be the "in" thing today. If you have found the single-bit method is too limited and the digital/analog converter approach too expensive, the low-cost (less than $30) Music Box described here may be just for you.

The Music Box has a 12-note, four-octave range. It can be used with any computer that has a parallel output port. And to simplify its use, no strobes or other handshake signals are required.

The Music Box circuit is not limited to making music. It can easily be pro-



PARTS LIST

C1, C2—0.01-μF Mylar capacitor
D1 through D12—1N914 diode
IC1—74154 4-line to 16-line decoder
IC2—555 timer
IC3, IC4—7473 dual JK flip-flop
IC5—7400 quad NAND gate
Q1—2N3904 transistor
R1 through R13—5000-ohm linear-taper pc trimmer potentiometer
The following are 1/4-watt, 5%-tolerance resistors:
R14, R15, R19, R20—1000 ohms
R16—10,000 ohms
R17—22,000 ohms
R18, R21, R22, R23, R24—100,000 ohms
Misc.—IC sockets (optional); suitable prototyping board; suitable enclosure; etc.

As bits 0 through 3 from computer change, the vco changes frequency. Other four bits (4 through 7) determine the octave of the audio output.

grammed to generate a mix of tones, up to a total of 16, for use as test and remote-control signals.

Circuit Operation. The circuit (see schematic diagram) can be broken down for discussion purposes into three major subsections: note decoder/selector, voltage-controlled oscillator (vco), and octave decoder/selector.

The note decoder/selector consists of integrated circuit *IC1*, a 4-line to 16-line decoder. As the four control bits from the computer (bits 0, 1, 2, and 3) are entered into *IC1*, one of the 16 output lines is driven low. When the output line goes low, it allows its associated diode (*D1* through *D12*) and series potentiometer (*R1* through *R12*) to control the voltage and, hence, the frequency of the vco made up of *IC2*, *Q1*, and their associated components. Since only 12 tones per octave are used in music, output lines 13, 14, and 15 of *IC1* (pins 15, 16, and 17) are not used. (These three lines can be used to control an external device, as we will discuss later.) When *IC1*'s output 0 at pin 1 is low, the vco is cut off to provide a no-note condition.

Timer *IC2* is configured as an oscillator, with transistor *Q1* serving as a voltage-controlled resistor that works in conjunction with frequency-determining capacitor *C1*. By varying the bias applied to the base of *Q1*, the output frequency of the vco system can be made to vary.

Resistor *R18* determines the low- and *R16* and *R17*, the high-frequency ends of the range. Capacitor *C1* can be

TABLE I— THE WELL-TEMPERED MUSICAL SCALE

Control bit 76543210	Frequency (Hz)	Note 5th Octave
10000000	0	Off
10000001	523.25	C
0010	554.37	C#
0011	587.33	D
0100	622.25	D#
0101	659.26	E
0110	698.46	E#
0111	739.99	F
1000	783.99	G
1001	830.61	G#
1010	880.00	A
1011	932.33	A#
1100	987.77	B

changed to select the desired frequency range. The output of the oscillator at pin 3 is fed to the flip-flops in *IC3* and *IC4* for octave generation.

The four octaves of square waves generated by *IC3* and *IC4* are summed with the four octave-control bits (bits 4, 5, 6, and 7) by the four AND gates in *IC5*. The resulting selected octaves are mixed in *R21* through *R24* for application to an external audio system. Any combination of four octaves can be selected simply by changing the status of bits 4 through 7. If all octave bits are low, no tone appears at the output. Note that no status signals are required.

Since the audio output consists of square waves, it is not difficult to introduce various types of filters to create different sounds.

Construction. The entire circuit can be assembled on any prototyping board that can be connected to the parallel output port of the computer in which the Music Box is to be used. The power for the Music Box can be taken from the +5-volt and ground lines in the computer. Alternatively, you can use an external power supply rated at 100 mA minimum. In either case, a common ground must be used between the Music Box and computer.

You can use sockets for the IC's if you wish and small board-mounted trimmer potentiometers for *R1* through *R13*.

Calibration. Although the Music Box was designed for use with a computer, it does not require a computer for calibration. All you need is a 5-volt dc power source and an audio system. A frequency counter will simplify calibration but is not a necessity.

Before applying power to the Music Box, set *R1* through *R12* to their maximum series resistance and *R13* to its center of rotation. If you have a frequency counter, connect it to the TEST POINT. Otherwise, connect the output of the Music Box to an amplifier/speaker combination so that the pitch of the output signal can be compared with the sound of a known musical instrument.

Using temporary jumpers to the +5-volt (1) and ground (0) lines, set the control bits to the values given in Table I and adjust the corresponding trimmer potentiometer (*R1* through *R12*) to obtain the indicated frequency (or the correct tone when compared with the sound from a musical instrument). If the entire range cannot be obtained, readjust *R13* and perform the above procedure again.

TABLE II—TEST VALUES

Note	Number value (n)
Off	0
C	1
C#	2
D	3
D#	4
E	5
E#	6
F	7
G	8
G#	9
A	10
A#	11
B	12
Octave	**Number value**
5	n + 128
4	n + 64
3	n + 32
2	n + 16

Note: B_5 is the highest note (n = 140)
C_2 is the lowest note (n = 17)
C_5 is middle C
A_4 is A_{440}

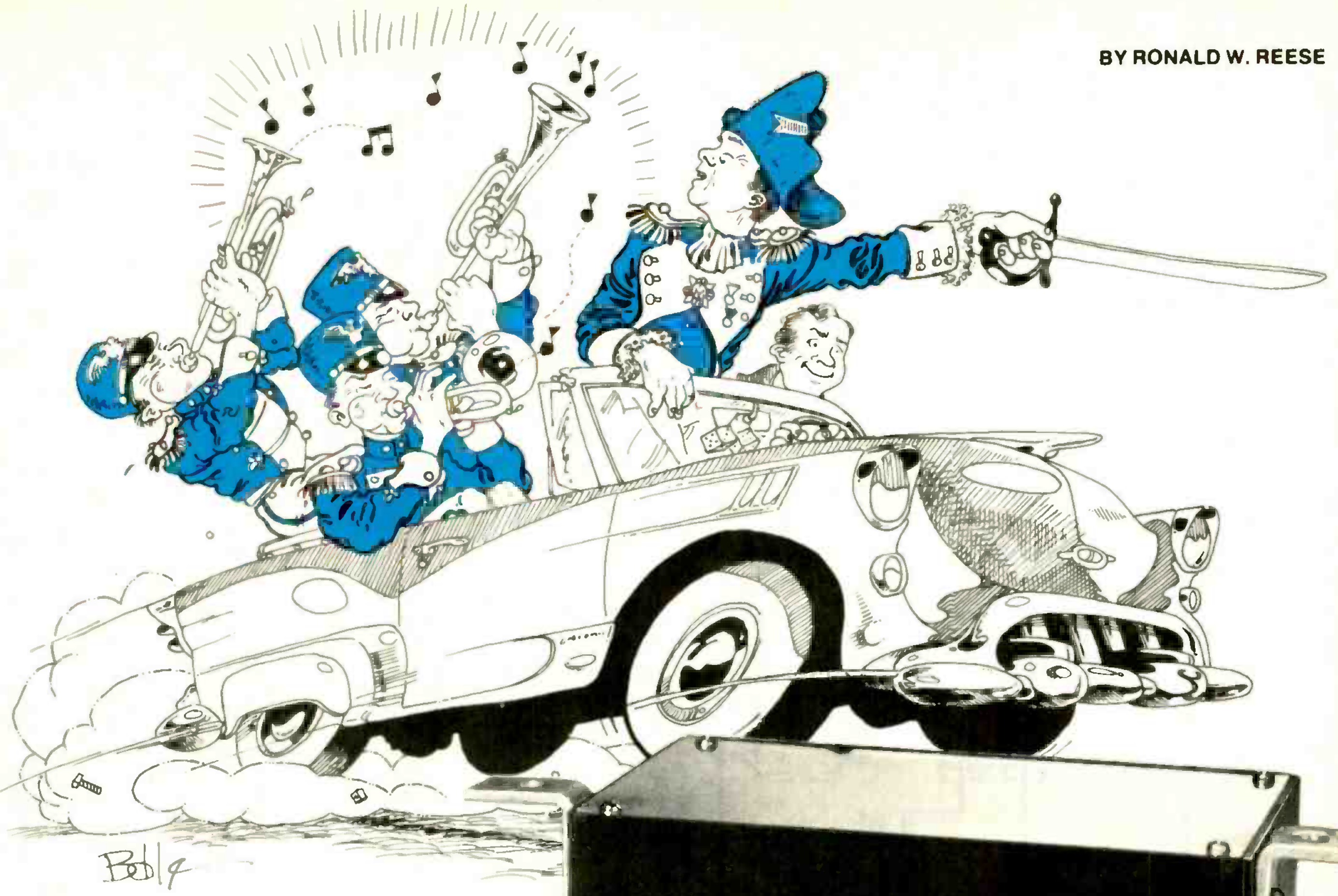
Operation and Use. Since there is no data latch, the Music Box tracks the data that appears at the parallel output port. Connect the common ground and eight data lines between the Music Box and the output port. To test the system, execute an output of the number value that corresponds to that note as given in Table II.

The software program you write will depend on the music requirements. Arrays can be used to store melody information and loops can be used to control the length of the note.

The four-octave range of the circuit can be shifted by either halving the value of *C1* to raise the pitch one octave or it can be doubled to lower the pitch one octave.

Other Uses. The three decoded outputs from *IC1* at pins 15, 16, and 17 can be used to trigger a percussive device or to latch an external control device. These decoded output signals are TTL level. If, however, music is not what you want, you can use the circuit to provide sixteen preadjusted tones for use in testing or remote-control applications. To obtain all sixteen tones, you must add diodes and potentiometers to the circuit as shown for the other outputs. ◇

BY RONALD W. REESE



BUILD "Charge!"

A digital electronic bugle-call generator with an audio amplifier for mobile or home use.

IF YOU have ever seen a Western movie, you're no doubt familiar with the bugle call played as the U.S. Cavalry charges over the hill to the rescue. This project generates that bugle call electronically. Because digital circuitry establishes the musical intervals between the notes, it will never drift out of tune. "Charge!," as the project is called, can be built from readily available, inexpensive TTL logic, 555 timer IC's, and silicon transistors.

Two versions of the circuit are presented. One, incorporating a high-power output stage, requires a 12-volt dc supply and is well suited for use as a vehicle horn or a cheerleading device at parades and school sporting events. The low-power version, operated from the ac line, can be used as an annunciator, doorbell, alarm, or simply as an attention-getting conversation piece. Two controls allow the user to vary both the tempo and pitch of the bugle call.

About the Circuit. Free running timer *IC1* and its associated components (Fig. 1) form a tone oscillator whose operating frequency is governed by the setting of *R2*. The oscillator output, a square wave with a duty cycle close to 50%, is frequency divided by factors of 10, 12, and 15 by *IC2*, *IC3*, and *IC4*, respectively. In this way the three tones that form the bugle call melody are generated. Digital frequency division ensures that the intervals between the three notes remain constant. However, the pitch of the bugle call can be varied by adjusting *R2*.

Square waves from *IC1* are applied to the three frequency dividers simultaneously. The 7490 functions as a symmetrical ÷ 10 counter in the following manner. Input signals are routed to the internal ÷5 counter (pin 1). The output of this counter is connected to the input (pin 14) of the IC's ÷2 counter. Output signals appearing at pin 12 have a frequency one-tenth that of the input and a duty cycle of 50%. A ÷12 counter (*IC3*) is formed in a similar manner by interconnecting the ÷6 and ÷2 counters contained in a 7492 IC.

A different approach must be taken to realize a ÷15 function because 15 is not divisible by two and some other integer. In this project, a 74193 presettable up/down counter is used as the ÷15 stage. This counter IC has four data inputs (pins 15, 1, 10 and 9) and four corresponding outputs (pins 3, 2, 6 and 7). The counter outputs can be preset to

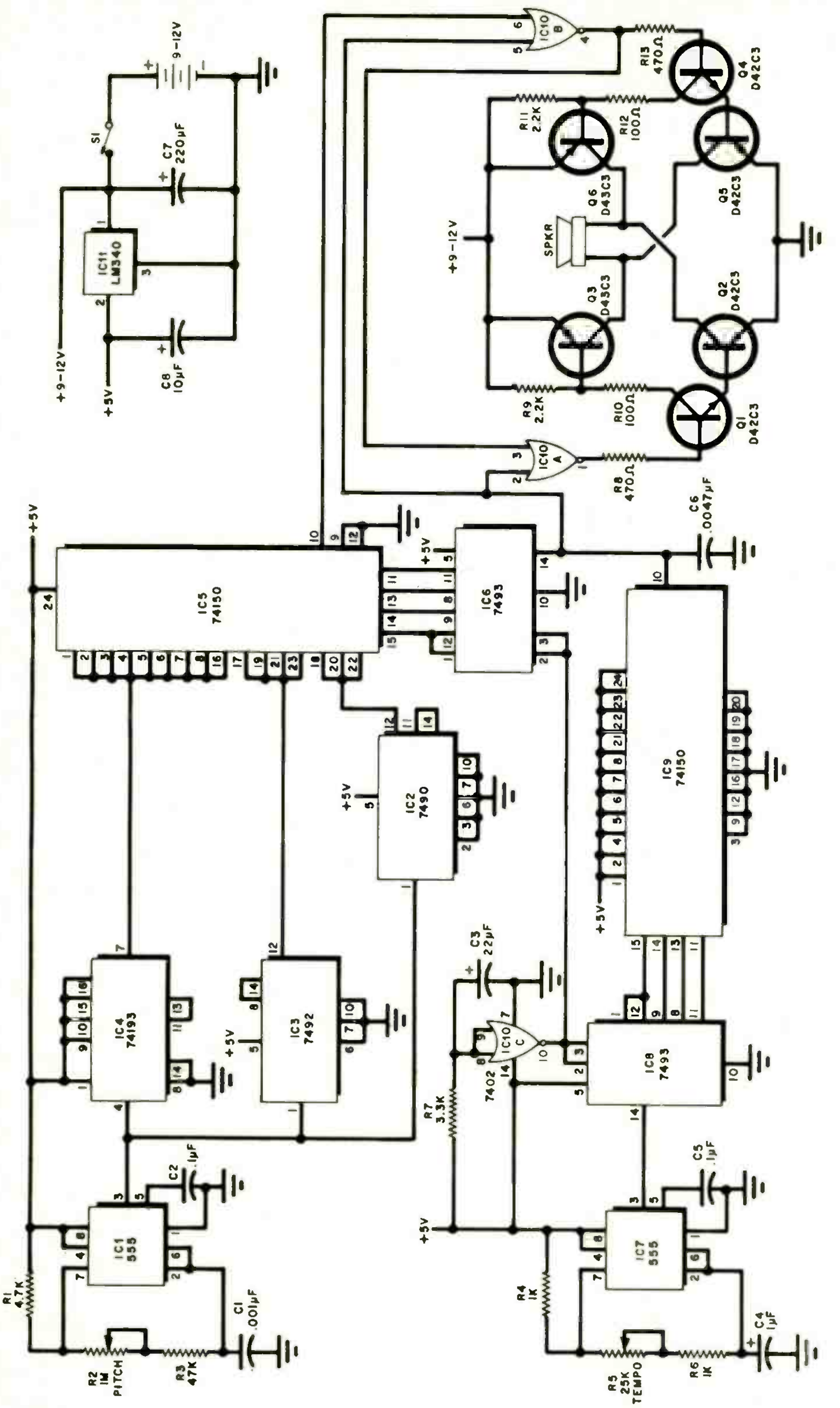


Fig. 1. Schematic diagram of "Charge!" Tempo and musical notes of the bugle call are generated digitally.

PARTS LIST

C1—0.001-µF disc ceramic capacitor
C2, C5—0.1-µF disc ceramic capacitor
C3—22-µF, 16-V electrolytic capacitor
C4—1-µF, 16-V electrolytic capacitor
C6—0.0047-µF disc ceramic capacitor
C7—220-µF, 16-V electrolytic capacitor
C8—10-µF, 16-V electrolytic capacitor
IC1, IC7—NE555 timer
IC2—SN7490 decade counter
IC3—SN7492 ÷ 12 counter
IC4—SN74193 synchronous 4-bit binary up/down counter IC with preset inputs
IC5, IC9—SN74150 16-line to 1-line data selector/multiplexer
IC6, IC8—SN7493 4-bit binary counter
IC10—SN7402 quadruple 2-input NOR gate
IC11—LM340 5-volt regulator
Q1,Q2,Q4,Q5—Silicon npn power tab transistor (GE D42C3 or equivalent)
Q3, Q6—Silicon pnp power tab transistor (GE D43C3 or equivalent)
The following are ¼-W, 10% carbon resistors:
R1—4700 ohms
R3—47,000 ohms
R4,R6—1000 ohms
R7—3300 ohms
R8,R13—470 ohms
R9,R11—2200 ohms
R2—1-megohm linear taper potentiometer
R5—25,000-ohm linear taper potentiometer
R10,R12—100-ohm, 1-W, 10% carbon composition resistor
S1—Spst 3-ampere switch
SPKR—8-ohm, 15-W weatherproof horn speaker
Misc.—Printed circuit or perforated board, IC sockets, suitable enclosure, control knobs, heat sink (if necessary), heat sink paste, screw-type terminal strips, machine hardware, hookup wire, solder, etc.

form a four-bit binary number by applying four bits to the data inputs and grounding the load input (pin 11) momentarily. When this is done, the four bits applied to the inputs appear at the outputs.

After the load input returns to the logic one state, the IC can count down if pulses are applied to the count down input (pin 4) while the count up input (pin 5) is at logic one, or count up if pulses are applied to the count up input while the count down input is at logic one. In this application, the 74193 is used as a down counter. It is loaded with the binary number 1111 (15_{10}), and is then allowed to count down as pulses are received from *IC1*. When the counter output reaches 0000 (0_{10}) and the count down input falls to logic zero, a logic zero appears at pin 13, the borrow output of the IC.

The logic zero at the borrow output indicates that 15 pulses from *IC1* have been counted by *IC3* and that the IC must be preset again to 15 for the next counting cycle. By connecting all data

inputs to the +5-volt supply and the bo-
row output to the load input, the counter
will automatically preset itself to 15 ...are
it has counted down to zero. If the
waves appearing at the Q o...sed as
counter's D flip-flop (pin ...ge. The
the output signal from ... logic one
output of this flip-flop ... at logic
for seven pulses ... results in a
zero for eight ... which is rea-
duty cycle ...lector is formed
sonably ...ne data selector/
...a 7493 four-bit bi-
... from the beat gen-
...re discussed later, are
...ver the range 0000_2 to
...ary number generated by
...to the data select inputs of
...ounts upward, *IC5* sequen-
...s signals from frequency di-
..., *IC3*, and *IC4*. The three
...oduced by the counters appear
...data inputs of *IC5* in the order in
...n they appear in the bugle call. In
...s way tones are selected and gated in
...roper sequence for application to the
power amplifier.

The tempo at which the call is played is governed by the beat generator. This circuit also establishes the timing relationships between the notes and rests, and supplies a clock signal to counter *IC6* in the tone selector circuit. The beat generator is formed by interconnecting *IC7*, a free-running 555 timer, *IC8*, a 7493 four-bit binary counter, and *IC9*, a 74150 16-line to 1-line data selector/multiplexer. The oscillating frequency of *IC7*, determined by the setting of potentiometer *R5*, sets the amount of time allotted to each beat.

A repetitive beat can be used due to the nature of the song. The notes in the bugle call are played in pairs. That is, one note is played, followed by a short rest, and then the next note is played, followed by a longer rest. All notes are of the same duration—five beats. The short rest separating the two notes forming a pair is one beat long. The longer rest separating pairs of notes is five beats long. Therefore, a total of 16 beats is required by one pair of notes and two rests (one short, one long).

Binary counter *IC8* will count 16 pulses and automatically overflow to zero, providing a convenient way to determine the passage of 16 beats. The four binary outputs of the counter (pins 12, 9, 8 and 11) are connected to the four data select inputs of multiplexer *IC9*. The data inputs of the multiplexer are connected to either +5 volts or ground. The first five inputs (zero through four, pins four through eight) are tied to the +5-volt line. An internal NOR gate is the multiplexer's output stage, so a logic zero appears at pin 10 (the multiplexer output) for the first five beats. This allows NOR gates *IC10A* and *IC10B* to pass an inverted version of the output signal at pin 10 of multiplexer integrated circuit *IC5*.

Input five (pin 3) of multiplexer *IC9* is connected to ground, so a logic one appears at the multiplexer's output on the sixth beat. This causes the outputs of *IC10A* and *IC10B* to remain at logic zero regardless of what is applied to the other input of each gate. No signals can pass to the power amplifier during this interval, resulting in a one-beat rest. Inputs six through ten, pins 2, 1, 23, 22, and 21, are connected to +5 volts. When *IC9* selects input six, its output goes low, causing two things to happen. Decade counter *IC6* counts up one pulse, allowing *IC5* to select the next note. Also, NOR gates *IC10A* and *IC10B* pass signals from the tone multiplexer to the power amplifier. The output of *IC9* remains low through the tenth beat.

The last five inputs, 11 through 15 at pins 16 through 20, are connected to ground. This causes the output of *IC9* to go high, disabling the power amplifier. By this time, two notes have been played and the beat generator counter, *IC8*, has overflowed to 0000 and the beat sequence will repeat itself. The sequence must be repeated eight times for

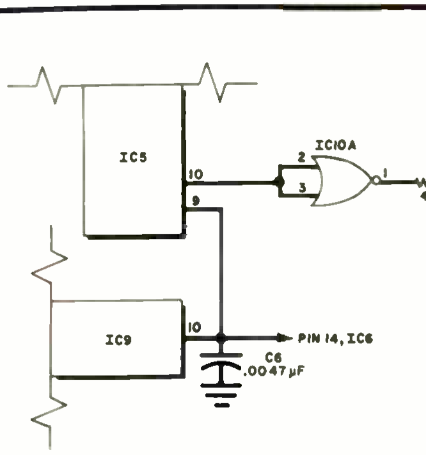


Fig. 2. Output stage for the low-power version.

LOW-POWER OUTPUT STAGE PARTS LIST

R14—50-ohm wirewound 5-W potentiometer
SPKR—8-ohm, 5-W speaker
Misc.—Hookup wire, small enclosure if speaker is mounted remotely, machine hardware, terminal strip, solder, etc.

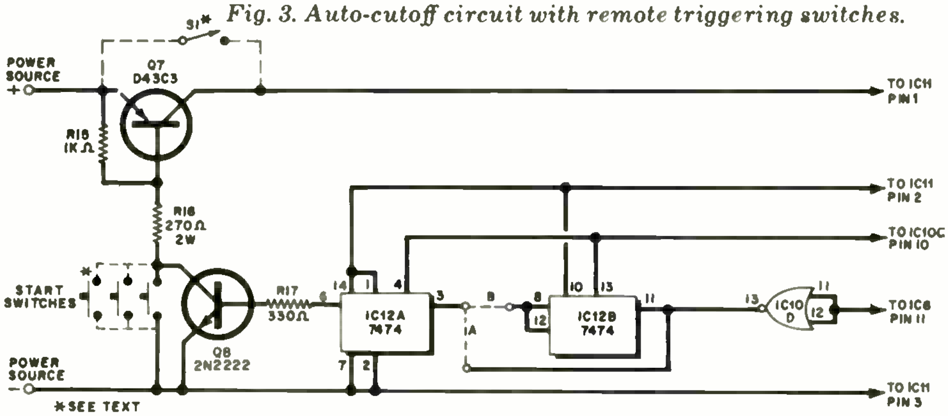


Fig. 3. Auto-cutoff circuit with remote triggering switches.

AUTOMATIC CUTOFF PARTS LIST

IC12—SN7474 dual D-type edge-triggered flip-flop
Q7—Silicon pnp power tab transistor (GE D43C3 or equivalent)
Q8—2N2222 npn switching transistor
The following are 10% carbon composition resistors.
R15—1000 ohms, ½ W
R16—220 ohms, 2 W
R17—330 ohms, ½ W
S1—Spst 3-A switch (optional)
Misc.—Normally open momentary-contact pushbutton switches (optional), IC socket, heat sink, mica washer, heat sink paste, machine hardware, hookup wire, solder, etc.

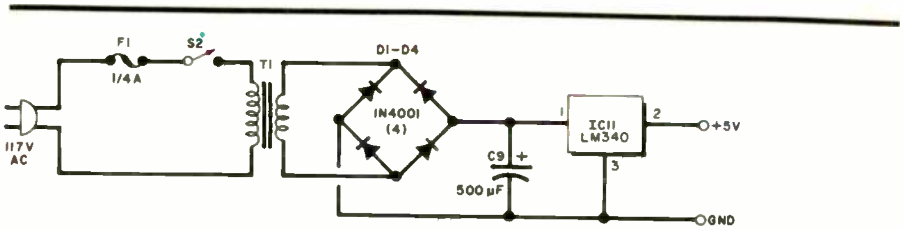


Fig. 4. Ac supply for low-power "Charge!"

LOW-POWER LINE-OPERATED SUPPLY PARTS LIST

C9—500-µF, 25-V electrolytic capacitor
D1 through D4—1N4001 silicon rectifier diode
F1—¼-ampere fuse
S2—Spst 1-ampere switch
T1—12.6-V, 1-A filament transformer

all the notes to be selected and played. When all notes have been played, both beat generator counter *IC8* and note selector counter *IC6* will overflow to 0000, and the bugle call will repeat until power is removed. An auto start circuit comprising *IC10C*, *R7* and *C3* ensures that *IC6* and *IC8* start counting at 0000 when power is applied.

Transistors *Q1* through *Q6* and resistors *R8* through *R13* form the power amplifier. The tone selected by *IC5* is applied to one input of *IC10B*. The output of this gate provides base drive for *Q4* and is also applied to one input of *IC10A*. Gate *IC10A* inverts and passes the signal to *Q1* when the output of *IC9* is low. When the square wave applied to *IC10B* goes low, the output of the gate goes high, turning on transistors *Q4*, *Q5*, and *Q6*, which energize the speaker. The logic one at *IC10B*'s output also produces a logic zero at the output of *IC10A*, cutting off transistors *Q1*, *Q2*, and *Q3*.

When the output of *IC10B* goes low, *Q4*, *Q5* and *Q6* are cut off, the output of *IC10A* goes high, and *Q1*, *Q2*, and *Q3* turn on. Current again flows through the speaker, but in the opposite direction. The transistors are, of course, turning on and off at the audio frequency of the selected tone. This arrangement is considerably more complex than the more commonly used switching circuits, but provides much more output power.

The amplifier draws current directly from the power source. The TTL integrated circuits, however, require +5 volts, which is provided by *IC11*.

Circuit Options. Your particular application might not require the high output power and/or continuous play capability of the circuit shown in Fig. 1. Therefore, a low-power output stage (Fig. 2) and an automatic cutoff circuit (Fig. 3) are possible options.

The manual cutoff, high-power circuit will start playing the bugle call each time power switch *S1* is closed. It will continue to play the call until *S1* is opened. This version of Charge! is suitable for use in a vehicle or as a cheerleading device. However, if the unit is intended for indoor use, the low-power output stage should be employed. (A line-powered supply for the low-power version is shown in Fig. 4.)

If Charge! is to be operated so that it plays the tune once after a momentary switch (such as a doorbell switch or magnetic door switch) closes, the automatic cutoff circuit should be included. Either circuit option can be employed separately, or both used together. The power supply shown in Fig. 4 can accommodate the auto cutoff as well as the low-power output stage.

The auto cutoff circuit controls power to regulator *IC11*. A momentary switch closure latches the circuit on until the bugle call has been played in its entirety. If the "A" wiring is used, flip-flop *IC12A* will then toggle and turn off *Q8*. This, in turn, cuts off pass transistor *Q7*. If the "B" wiring is used, *IC12A* will not toggle until the bugle call has been played twice. Of course, you can install an SPDT switch to select either the "A" or "B" connection. Similarly, you can connect power switch *S1* across *Q7* to provide a choice of either continuous or automatic cutoff operation.

Transistors *Q2* through *Q6* and resistors *R9* through *R13* are omitted in the low-power output stage. Gate *IC10A* inverts the tone square waves at the output of multiplexer *IC9* and applies them to the base of *Q1*. When the output of *IC10A* is high, *Q1* conducts and current flows through the speaker. Potentiometer *R14* functions as an output level control. When the output of *IC10A* is low, the transistor is cut off and the speaker coil passes no current. Referring to the previous description of the high-power output stage, it can be seen that the average current through the speaker is doubled by that circuit as compared to

the low-power stage. This results in a fold increase in output power. If ...decide to employ the low-power ...e to connect the output of ...o the strobe input of ...the strobe input is ...tput remains ...s appear ...log-

fo...
If...
stage...
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ic zero at the stro...
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put. All other connecti...
same whether the high-...
output circuit is used.

Construction. Printed circuit... to-point, or Wire Wrap assembly niques can be used. Parts placeme... not critical. Wire Wrap sockets sho... be used with the IC's if this method duplicating the circuit is chosen. Wire n... smaller than No. 24 should be used fo... all power supply and output stage connections. All ground connections should be made to one common point.

If Charge! is housed in a metallic utility box, *IC11* should be mounted on the enclosure with thermal coupling through heat sink paste. The utility box will then be connected to the circuit common or ground. If desired, a small heat sink approximately 1" x 1" (2.5 x 2.5 cm) with ½" (1.3-cm) fins can be used with *IC11*. A heat sink is a necessity if the project is housed in a nonmetallic enclosure.

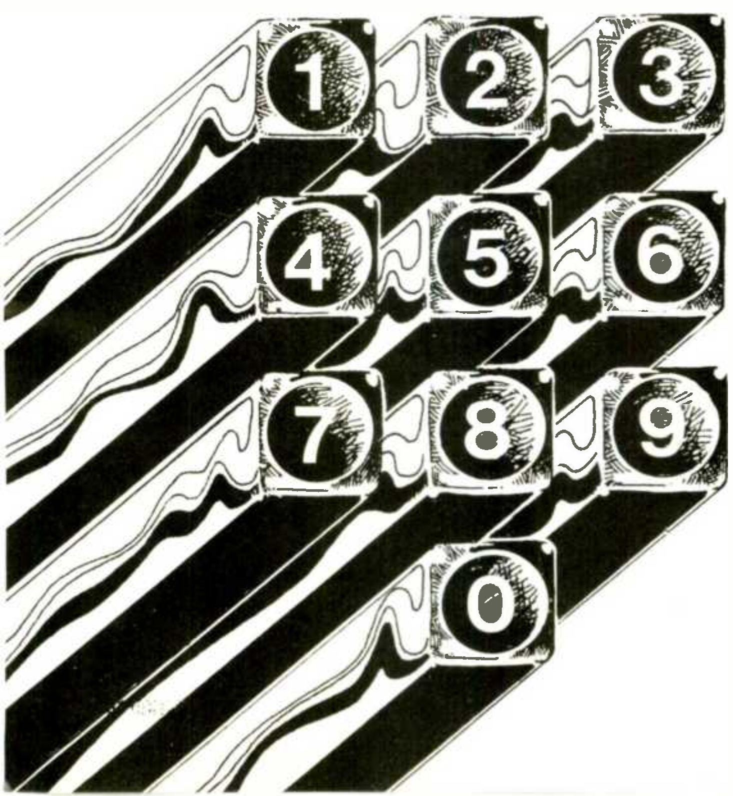
Power switch *S1*, PITCH control *R2*, and TEMPO potentiometer *R5* can be mounted at convenient spots on the enclosure. The power switch must be able to handle at least 3 amperes dc at 12 volts. If the automatic cutoff circuit is used, the momentary contact switches should be rated for 50 mA, and, if preferred, *S1* can be eliminated.

For automotive applications, tap +12 volts at a convenient point and route it to the project's power input. (Screw-type terminal strips mounted on the project enclosure simplify connections.) If the circuit is housed in a metallic enclosure, bolting it to the vehicle chassis will furnish a ground return. When connecting a speaker to the audio output, note that both sides of the speaker coil are floating. It's important, therefore, not to let one side of the speaker become inadvertently grounded. Mount the speaker, which should be a horn-type transducer for outdoor use, in or on the vehicle at a suitable location. The box housing the circuitry should be installed so that the power switch, TEMPO and PITCH controls can be easily reached. ◇

BY CLEMENT S. PEPPER

THE VERSATILE KEYPAD

How to interface these important mechanical devices with digital circuits.



THERE ARE an ever-increasing number and variety of low-cost decimal and hexidecimal keypads available to the electronics experimenter. To successfully use these keypads, one must observe certain criteria to be sure mutually compatible signals are available. You cannot just connect any keypad to any circuit and expect the system to operate properly. Either the keypad selected must be specifically designed for the digital circuit it is to drive, or the digital circuit must be designed to suit the specific keypad.

One major problem with keypads (and most other mechanical switches) is that they are not ideal switches. Instead of producing a single pulse when they are opened and closed, they produce a "train" of brief pulses as they mechanically settle. In ordinary switching applications, this "bouncing" is not a problem. But when switches are used with high-speed electronic counters, each pulse within a train (Fig. 1) can appear as a separate toggle signal, resulting in false counting.

Most keypads are decimal (0 to 9), while many electronic circuits require a binary-coded-decimal (BCD) input. Hence, a decimal-to-binary decoding system to make the conversion is required. Too, many counting circuits also require a "start" or "sync" signal to "tell" them when a key has been depressed. Therefore, some kind of key-closure sensing system must be used.

Debouncing. A basic debouncing circuit for a switch is shown in Fig. 2, accompanied by its truth table. The circuit consists of an AND and an OR gate. When the switch is closed, input A goes low and forces the output of the AND gate low. This low signal is connected to the C input of the OR gate and is additionally used to toggle the bounce-inhibit monostable multivibrator. In response to the low at its input, the multivibrator sends a low signal to the D input of the OR gate for a period of time determined by the monostable time constant. Since both inputs to the OR gate are low, the output of the gate also goes low.

The switch can now be released, causing the A input to go high, due to the pull-up resistor. With the low output of the OR gate connected to the B input, the output of the AND gate remains low. The circuit will remain in this state until the monostable time constant times out and sends a high signal to the D input of the OR gate.

As explained above, the very first closure of the switch causes the circuit to operate but locks out any subsequent bounce-produced signals. The only thing to keep in mind is that the bounce-inhibit monostable time constant must produce an output slightly longer than any expected bounce interval.

The circuit shown in Fig. 3 illustrates the use of the debounce circuit with a BCD coding scheme. A function truth table is also shown. You may be surprised to see a hexidecimal table for a 10-key array. If you wish to obtain a hex A (10),

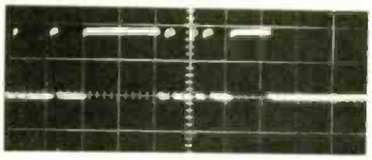
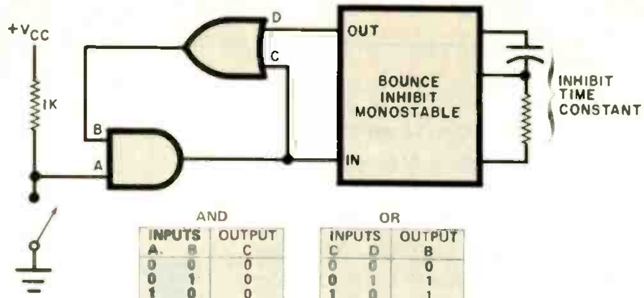


Fig. 1. Pulse train resulting from switch contact bounce. Sweep time is 50 μs/div.

both the 8 and 2 keys must be pressed simultaneously. Similarly, a hex F (15) requires simultaneous operation of the 8 and 7 keys. If you plan to use a hex keypad, use the same AND-OR gate logic for all 16 switches and substitute the circuit shown in Fig. 4.



AND

INPUTS A	INPUTS B	OUTPUT C
0	0	0
0	1	0
1	0	0
1	1	1

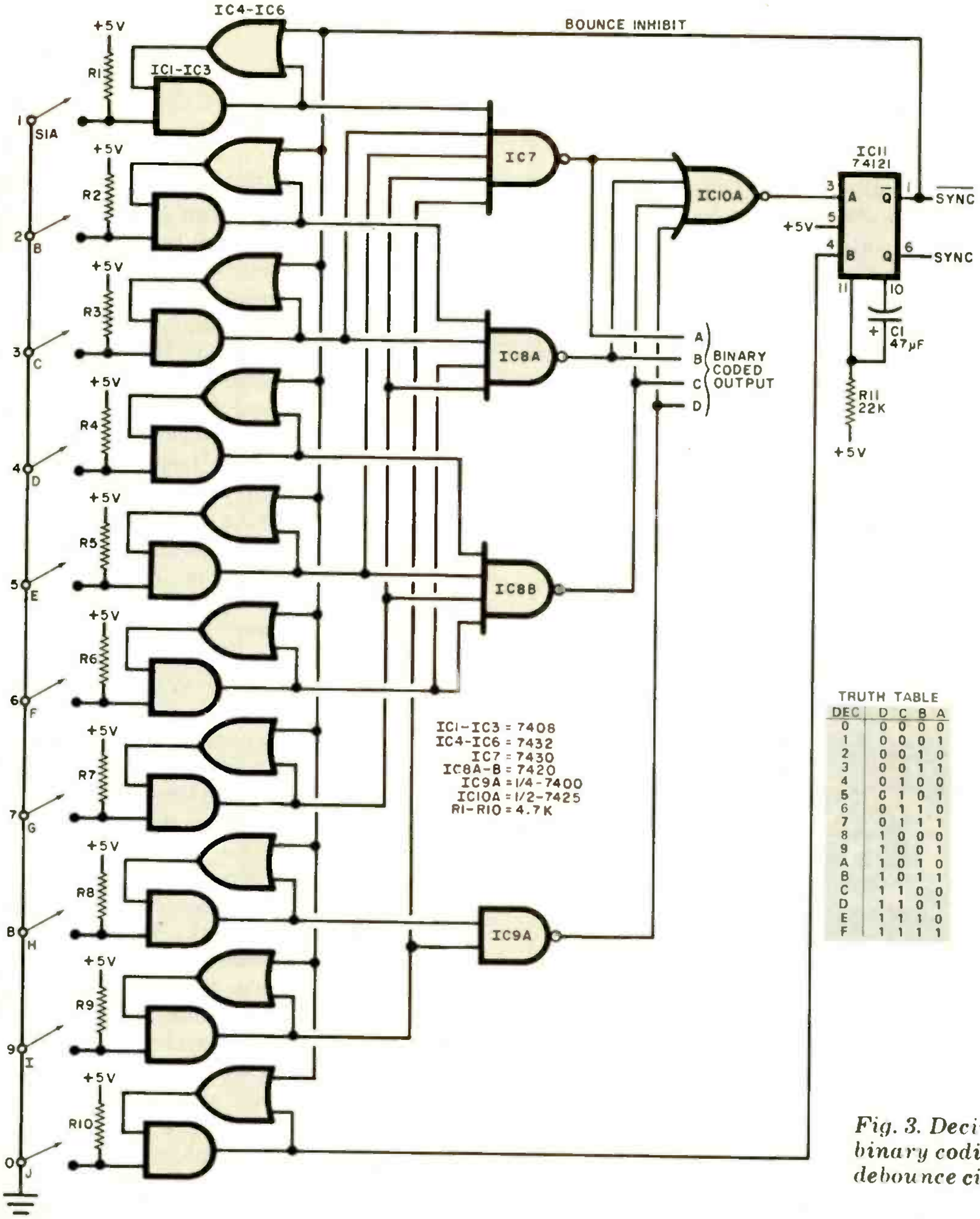
OR

INPUTS C	INPUTS D	OUTPUT B
0	0	0
0	1	1
1	0	1
1	1	1

SWITCH CIRCUIT LOGIC

STATE	A	B	C	D	
0	1	1	1	1	Switch open
1	0	1	0	1	Switch closure
2	0	0	0	0	Debouncer response
3	1	0	0	0	Switch bounce
0	1	1	1	1	Switch open, Debounce reset

Fig. 2. Switch debounce circuit is formed from AND-OR gate logic.



TRUTH TABLE

DEC	D	C	B	A
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1
A	1	0	1	0
B	1	0	1	1
C	1	1	0	0
D	1	1	0	1
E	1	1	1	0
F	1	1	1	1

Fig. 3. Decimal keyboard binary coding and switch debounce circuitry.

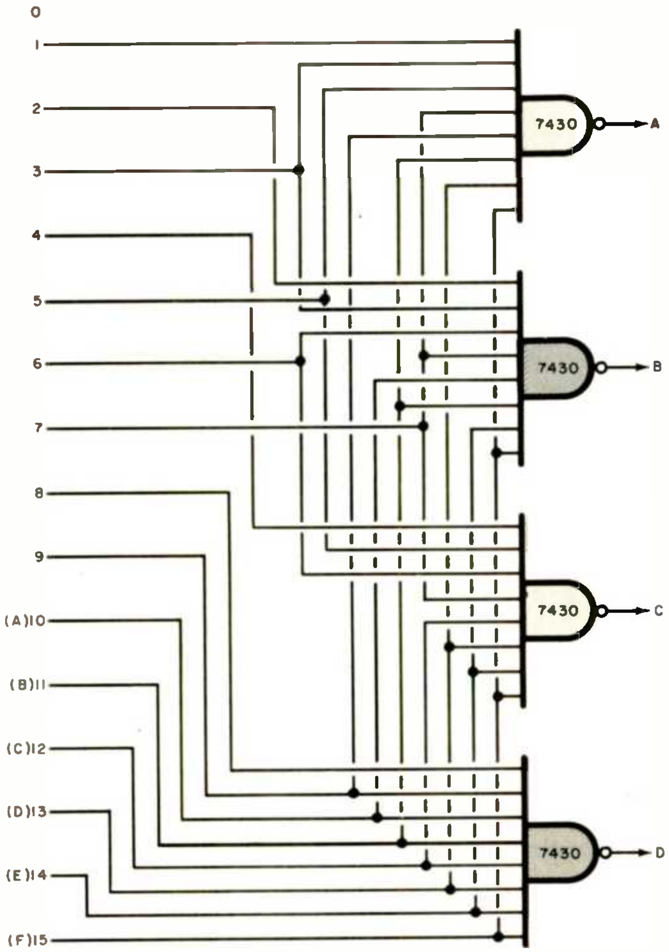


Fig. 4. Decoding logic for a hexidecimal keypad. This circuit is an addition to that in Fig. 3.

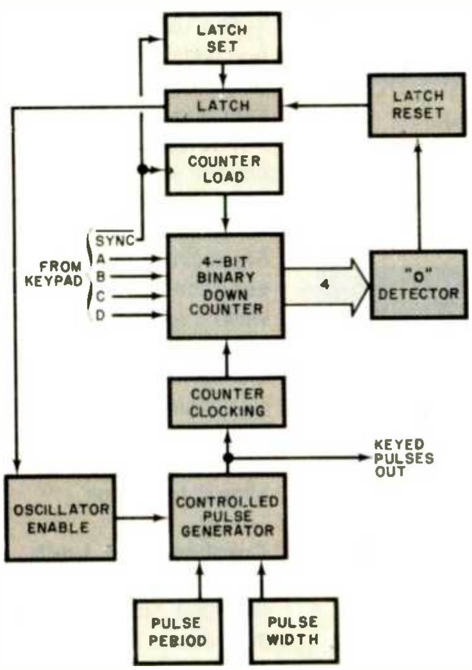


Fig. 5. Function diagram for a controlled-pulse generator.

Referring back to Fig. 3, when all keyswitches are open, their associated AND gate (*IC1* through *IC3*) inputs are high. Hence, the outputs of the four encoding NAND gates (*IC7* through *IC9*) are low. Closing any keyswitch except 0 forces at least one of the NAND gate inputs high.

The bounce-inhibit circuit uses a 4-input NOR gate (*IC10A*) to trigger bounce-inhibit monostable multivibrator *IC11*. When any of the four NOR gate inputs go high (any key closed), the output of the NOR gate goes low and triggers the multivibrator. The multivibrator, in turn, sends a low signal to the OR gate associated with each key. This implements the debounce function. For the RC values given in Fig. 3, the debounce period is about 700 ms. For the 74121 monostable multivibrator, the timing equation is $T = 0.69RC$, with R kept at a value of less than 40,000 ohms.

The circuit remains in the debounce condition and ignores any switch bounce until the monostable multivibrator times out. When this occurs, the circuit resets back to where another key can be operated. Note in Fig. 3 that the multivibrator also produces a "sync" signal in exact time step with the input pulse. This is for use with an external counting or other enabling circuit.

The 0 key requires a different approach from that discussed. Although it has the same debounce circuit as the other keys, when the 0 key is closed, a separate input trigger, B, on the multivibrator is used.

Controlled Pulse Generator. One use for a debounced and BCD-coded keypad is as a controlled pulse generator that delivers a number of output pulses determined by the decimal number inserted via the keypad. The basic logic for this circuit is shown in Fig. 5.

Pressing any key on the keypad in the Fig. 5 circuit sends a sync pulse to an enabling latch and the BCD-coded signal to the inputs of a binary down counter. The latch signal enables the counter's preset input and a controlled-pulse generator. The pulse generator is designed so that both pulse width and pulse period can be controlled. Each time a pulse appears at the ouput, the binary down counter is decremented by one. When the counter reaches zero, it resets the latch and stops the operation.

The actual circuit, shown in Fig. 6, is straightforward. The *IC1A/IC1B* latch is made from conventional TTL NAND gates, with RC coupling at the inputs to

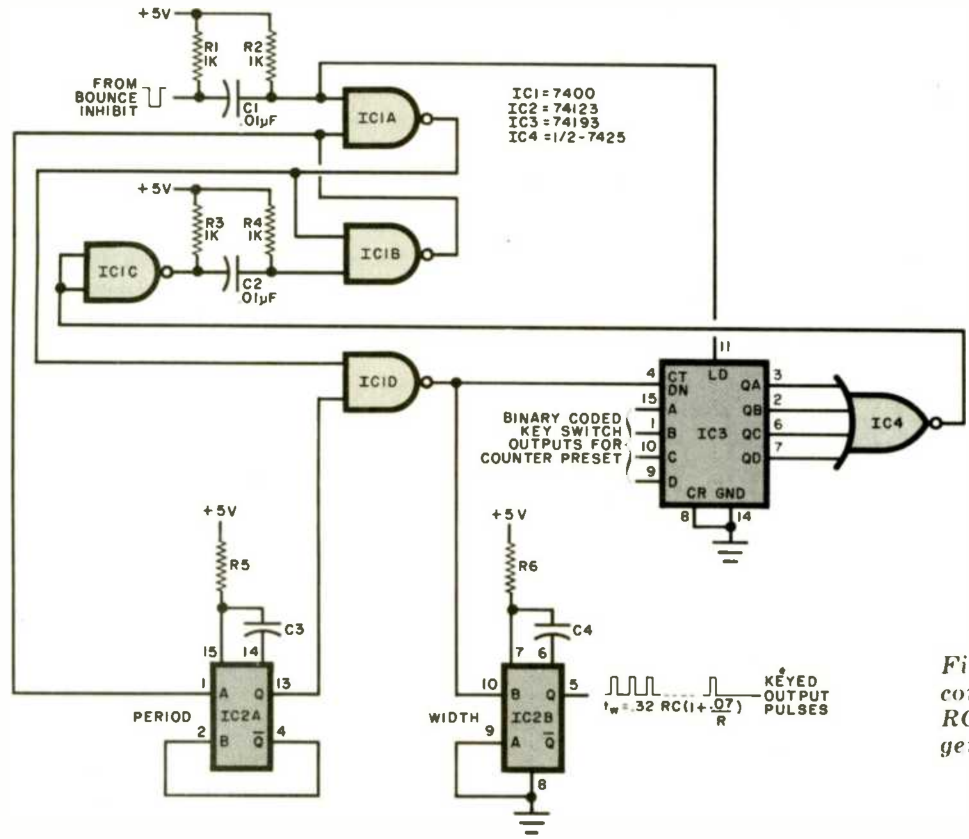


Fig. 6. Schematic of controlled-pulse generator. RC coupling allows generation of fast pulses.

allow rapid action—in fact, a complete pulse train can be generated within the width of the sync pulse. Without RC coupling, the latch would be locked for the duration of the sync time. A transient input is a must to avoid lockout. The *IC3* down counter has its LOAD enable input RC coupled to the sync input. This input requires a transient input to operate.

The controlled-pulse generator (*IC2*) is made up of both halves of a 74123 dual monostable multivibrator. The RC timing of *IC2A* sets the pulse period. The Q output at pin 13 is connected to NAND gate *IC1D*, with the second input of this gate connected to the latch. With the latch reset, the NAND gate is locked and its output remains in the high state, regardless of what the multivibrator is doing. In reality, *IC2A* is not doing anything, since its A input trigger at pin 1 is also enabled by the latch.

The first cycle of the operation is initiated when the latch is set. This causes a high-to-low transition at the A input. When the multivibrator triggers, the Q output at pin 4 goes low. When the multivibrator times out, the low-to-high transition at the Q output retriggers the multivibrator. Because the transition is so fast, the multivibrator appears to be continuously in the triggered state.

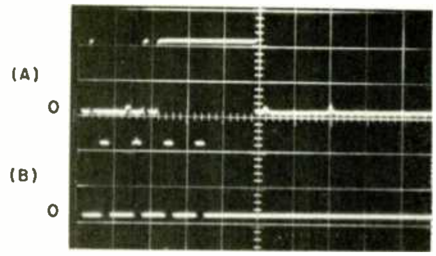


Fig. 7. Scope trace (A) shows switch bounce, while (B) shows four pulses initiated by switch closure. Sweep time is 50 µs/div.

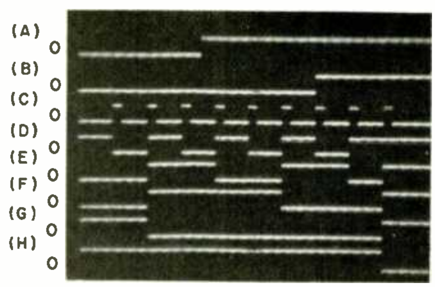


Fig. 8. Nine pulses generated by key switch closure (50 ms/div): (A) key closure; (B) sync; (C) outputs of 74123; (D) output QA; (E) output QB; (F) output QC; (G) output QD; all of IC3; and (H) latch input to IC1D.

The output of gate *IC1D* decrements the *IC3* counter and triggers the second monostable multivibrator (*IC2B*). The timing of this circuit controls the width of the pulse.

The only limitation on the frequency and width of the keyed pulses are those determined by the multivibrators. Very long and very short pulses over almost any range can be generated once the counter is preset. The keypad plays no role in this part of the operation.

The oscilloscope waveforms for the Fig. 6 circuit are shown in Fig. 7. The upper trace shows switch contact bounce, while the lower trace shows four pulses initiated by the first switch closure. Note the immunity to switch noise and the fast response possible. The traces in Fig. 8 show the timing of those functions that will be helpful in understanding the operation of the circuit.

Combination Lock. The logic for a four-digit combination lock that can be operated only by someone who knows the code is shown in Fig. 9. This circuit can easily be expanded so that several functions can be derived from a single keypad. Appropriate interfacing must be

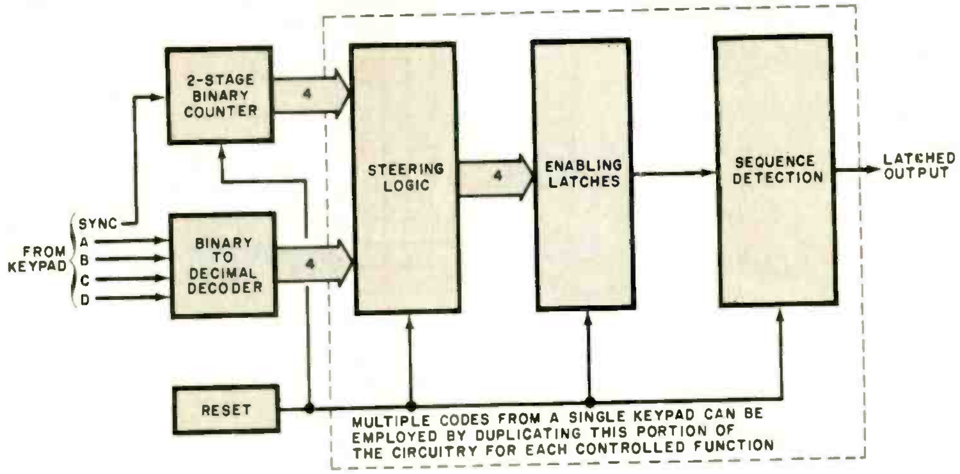
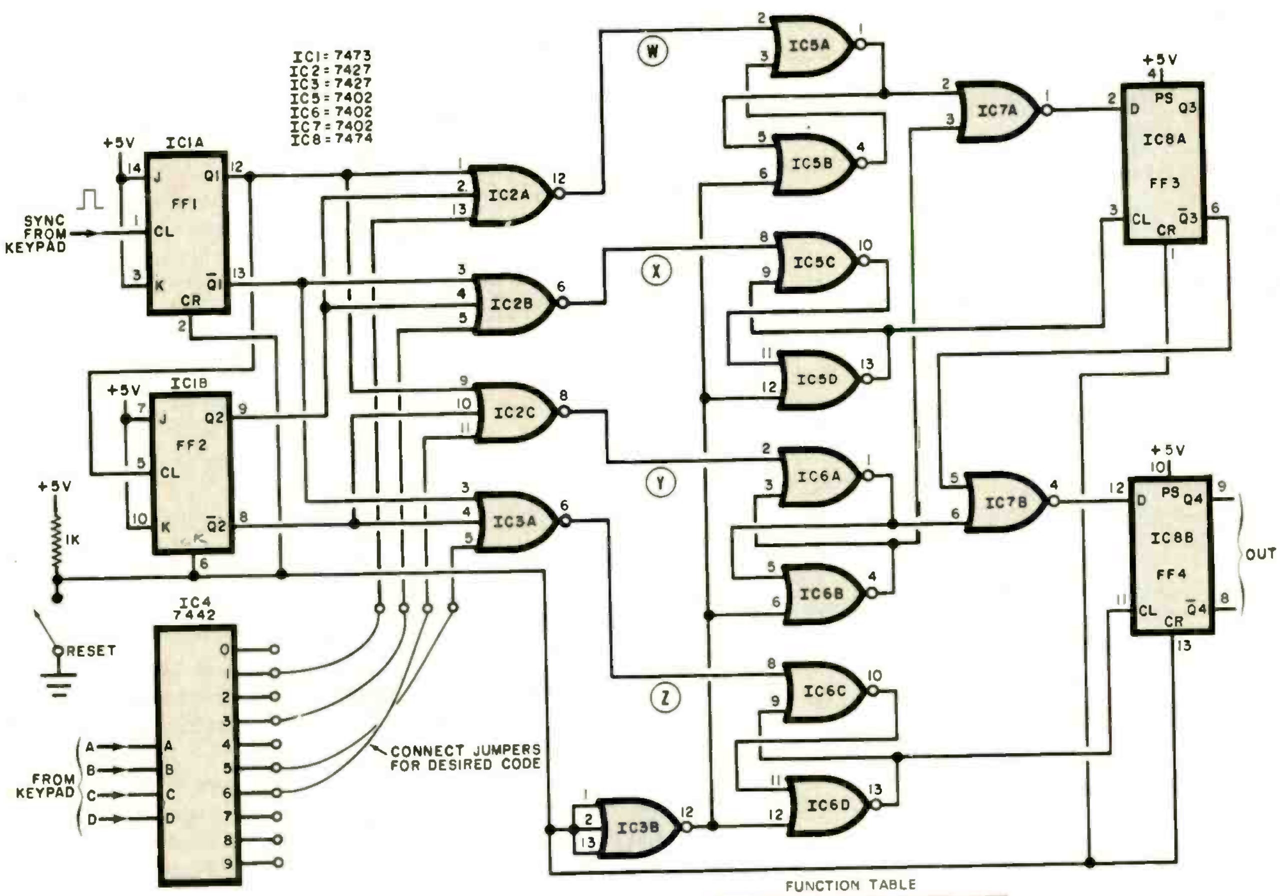


Fig. 9. Four-digit combination lock that works with only one selected set of input digits.



FUNCTION TABLE

DEC IN	FF2 $\bar{Q}_2$	FF2 Q_2	FF1 $\bar{Q}_1$	FF1 Q_1	LATCH IN W	X	Y	Z	FF3 $\bar{Q}_3$	FF4 Q_4
0	1	0	1	0	1	0	0	0	1	0
1	1	0	0	1	0	1	0	0	0	0
2	0	1	1	0	0	0	1	0	0	0
3	0	1	0	1	0	0	0	1	0	1

Fig. 10. Four-digit lock with combination 1365. Keyed code must match jumpered connections to operate lock.

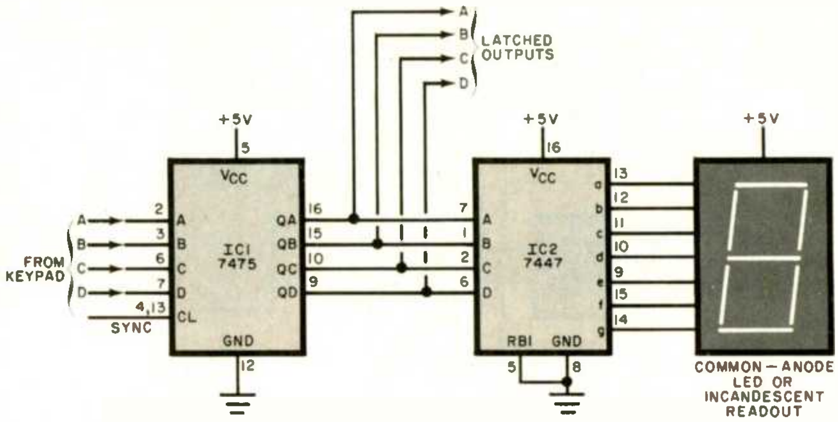


Fig. 11. Latched output for a keypad. Display is on a 7-segment LED readout.

added between the circuit and any external devices to be controlled. The actual circuit for the combination lock is shown in Fig. 10.

Operation of the lock begins with the reset mode. This is necessary because the reset can be initiated at any time in the event an incorrect digit is keyed. The output of a two-stage counter is decoded in the steering logic, and the BCD signals from the keypad are integrated into the counter's decoding logic so that a specific digit only can be passed through the enabling latches if both signals are coincident. It is mandatory that the four latches be set in the proper sequence (W,X,Y,Z) because any other combination will be defeated in the sequence detector.

A function table for the lock is given in Fig. 10. The 0 on the DEC IN line is the reset mode. The outputs of *FF1* and *FF2* assume a 0101 state. The *FF1* and *FF2* blocks are clocked flip-flops, with the clocking occurring on the trailing edge of the input pulse. The outputs of the keypad are fed to *IC4*, the outputs of which are selected to form the inputs to the associated NOR gates.

If the correct first digit is keyed in, line W goes to the high state, setting *IC5A*/*IC5B*. Both inputs to NOR gate *IC7A* are now low, setting the D input to *FF3* (*IC8A*) to high.

The sync pulse from the keypad has once more clocked the counter. If the second digit is correctly keyed in, line X goes high and sets the *IC5C*/*IC5D* latch. This clocks a low to one input of (*IC7B*). Once again, the keypad is operated with the correct digit to cause the associated latch to operate and placing a high on the Y line. This puts a low on the second input of *IC7B*. This sets the D input of *IC8B* to high.

The keypad is operated one more time with the final correct digit to set the Z line high. The Z latch clocks *IC8B* to change its output status. Either of the *IC8B* outputs can be used to interface to an external circuit.

If any of the four latches is set out of sequence, the clocking of *IC8A* and *IC8B* will be disrupted. The circuit is reset by operating the RESET switch.

Although the Fig. 10 circuit shows the use of a 1-to-10 decoder for the keypad input, a 1-of-16 decoder can be used for a hexidecimal input.

Switch Latch & Display. One difficulty with a keypad is that it is momentary. Once a key has been released, the action ceases. The addition of a quad latch, as shown in Fig. 11, will hold the switch outputs as long as dc power is applied. The *IC1* quad latch is used to drive BCD-to-7-segment decoder/driver *IC2* and a common-anode 7-segment LED display. This combination holds the last key depression and also produces a visible display of the digit depressed.

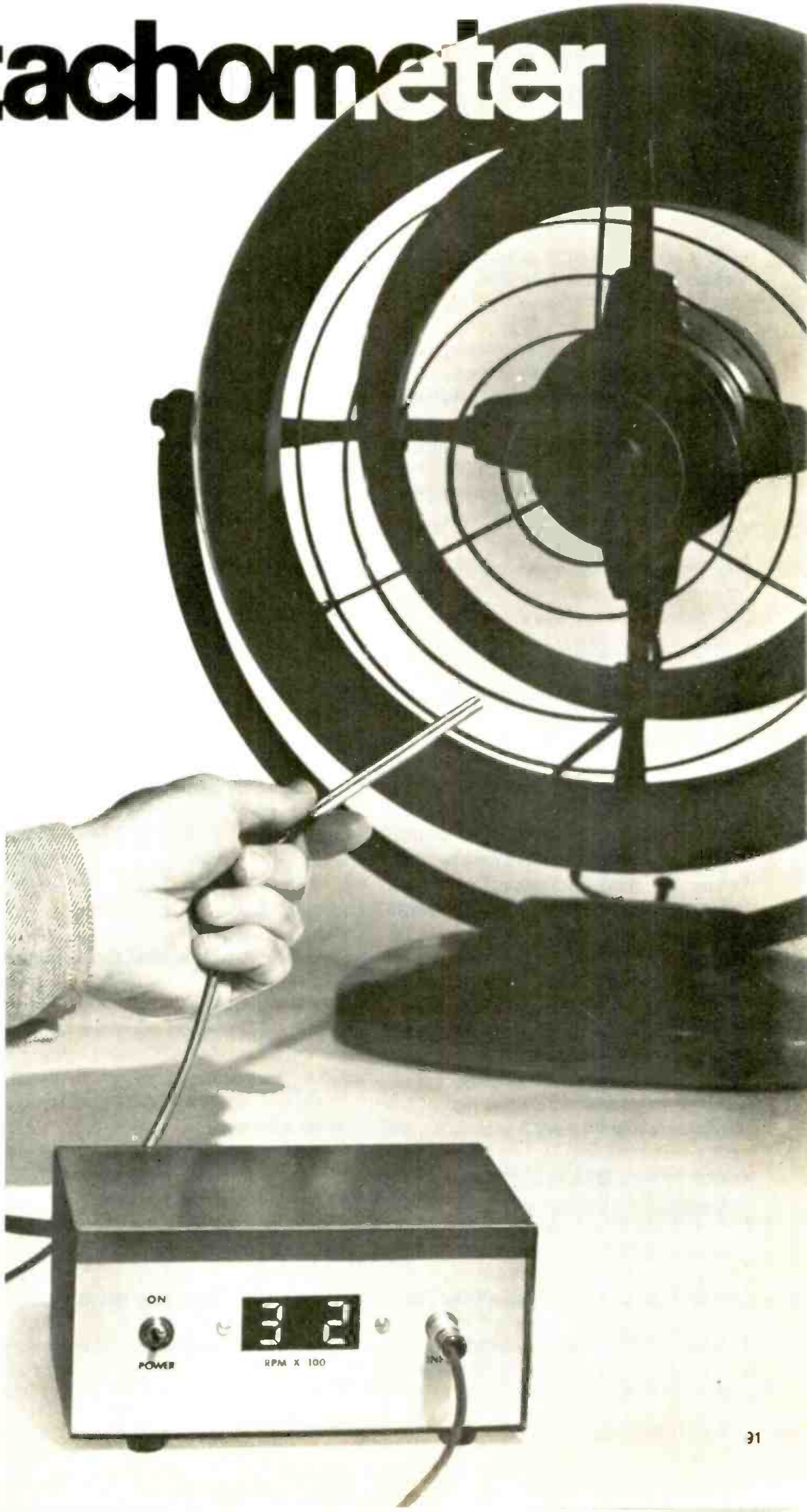
In Conclusion. In this article, we have described the major problems encountered when using mechanical switches—specifically keypad arrays—with digital circuits. We have offered some examples of how to deal with the problems and given hints on interfacing keypads with the electronic circuits. It is suggested that for further study and understanding of the material presented here you breadboard the circuits presented and do some experimenting on your own. ◇

BUILD A

By Walter Sikonowiz

Digital Phototachometer

Low-cost unit measures rotational speeds by optical coupling.



MOST ANALOG and digital tachometers require a mechanical or electrical interface with a rotating shaft. By contrast, this project, a digital phototachometer, measures rpm by optical means. It features a two-digit LED readout to display rotational speeds from 100 to 9900 rpm and a time base derived from the 60-Hz ac line, obviating the need for calibration adjustments.

Stability of the time base is good enough so that tach readings are accurate to the usual ±1-count uncertainty in the least significant digit. Modifications of the counting circuitry or sensing system can extend the measuring range one decade above 9900 or below 100 rpm, respectively. Total project cost is about $30.

Optical Sensing. As its name implies, the photo tach measures rpm by

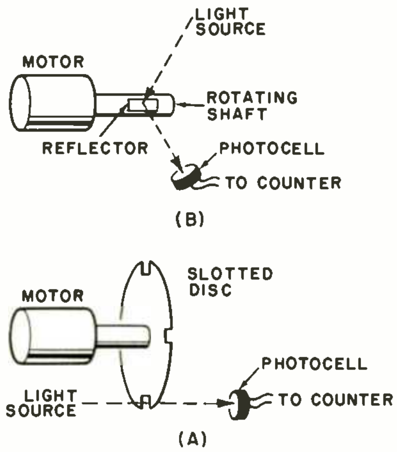


Fig. 1. Transmissive (A) or reflective (B) mode can be used to chop light for photosensor.

optical interaction with a rotating device. Measurements can be made by either of two basic means, which we'll call the transmissive and reflective modes. In the transmissive mode, the rotating device momentarily interrupts the optical path between a light source and a photosensor (Fig. 1A). This mode has limited usefulness. Although it's ideal for measuring the rotational speed of a fan or similar device, there are many situations in which it cannot be used. The transmissive mode requires a light chopper such as fan blades or a notched disc mounted on the motor shaft. If there isn't room enough to accommodate the chopper, this mode is impracticable.

The reflective mode is illustrated in Fig. 1B. A small strip of reflective tape is mounted on the motor shaft. If necessary, contrast can be increased by darkening the shaft background with black paint or tape. The light source and photo sensor are arranged so that light is reflected from the foil and toward the sensor as the shaft rotates.

About the Circuit. The schematic diagram of the phototach is shown in Fig. 2. Phototransistor *Q1*, the optical sensor, is connected to the rest of the project by a short length of shielded cable terminated with *P1*, an RCA phono plug. When *Q1* is illuminated by a chopped light beam, it alternately turns on and off. The resulting waveform at the collector of *Q1*, which approximates a square wave when the light beam is sharply chopped, is coupled by *C1* to *IC1*, a comparator used as a Schmitt trigger. Feedback provided by *R6* establishes the hysteresis that is characteristic of Schmitt trigger behavior.

Resistors *R2* through *R5* are close-tolerance components that maintain nearly equal biasing on the inverting and noninverting inputs of *IC1*. The output of the Schmitt trigger is a square wave compatible with the TTL integrated circuits forming a two-decade frequency counter.

Output pulses from *IC1* are gated by flip-flop *IC2*. The control signal for *IC2* is the time-base waveform, which is generated from the 60-Hz line in the following manner. Transformer *T1* and diodes *D2* and *D3* form a full-wave rectifier which develops a 120-Hz output. Diode *D4* isolates the cathodes of *D2* and *D3* from filter capacitor *C5*. The full-wave rectified sinusoid at the cathodes of the rectifier diodes is coupled to the base of *Q2* by *R11*.

This transistor saturates so easily that it converts the input waveform into a square wave appearing at its collector. The 120-Hz square wave is applied to *IC6*, a TTL ÷12 counter. Output signals from *IC6* are applied to *IC7*, another ÷12 counter. The net result is a square wave with a 50% duty cycle and a 1.2-second period. This is the time base that controls the gating and counter IC's.

Flip-flop *IC2* performs the gating function in a synchronous manner so that no spurious pulses reach the counters as a result of the gating process itself. The K input of the flip-flop is permanently grounded. Its J input is driven by the time-base signal, and output pulses from Schmitt trigger *IC1* are applied to the clock input. During the 0.6-second interval when the time base is at logic 1, pulses from *IC1* are gated to counter *IC3*. When the time base returns to logic 0, no more pulses are passed to the counter circuit.

The two-decade counter and readout comprises *IC3*, *IC4*, and *LED* displays *DIS1* and *DIS2*. TTL 74143 counter chips are employed in this project. They contain BCD decade counters, latches, and decoder/drivers. Current limiting is built in, so that the chips can be directly connected to the DL-747 common-anode displays.

Counter *IC4* counts the overflow pulses of *IC3*. The negative transition of the time-base waveform, which appears at the end of the 0.6-second counting interval, triggers one half of *IC8*, a 74123 dual monostable multivibrator. A negative-going, 100-microsecond wide pulse appears at pin 12 of *IC8*. This strobe pulse causes the transfer of data from the counter outputs into the latches. When pin 12 of *IC8* returns to logic 1, the second one-shot in *IC8* is triggered. A second negative-going pulse is generated, this time at pin 4 of *IC8*, which clears counters *IC3* and *IC4*. When the time base returns to logic 1, pulses are gated to the counter to repeat the process.

If more than 99 pulses are applied to *IC3* and *IC4* during the counting interval, the BCD outputs of both counters return to 0000 and *IC5* catches the overflow pulse from *IC4* in the following manner. Assume that the clear pulse has just appeared. This pulse not only clears the counters, but resets one half of *IC5*, a 7474 dual D flip-flop, so that the Q output (pin 5) is at logic 0. When the time base returns to logic 1, *IC3* and *IC4* begin to count. If more than 99 pulses are received, a positive transition occurs at pin 22 of *IC4*. This pulse is applied to the clock input of the first D flip-flop, causing the Q output to go to logic one.

The strobe pulse at pin 12 of *IC8* clocks the second flip-flop in *IC5* after the counting interval is over. This flip-flop's D input is connected to the Q output of the other flip-flop in the *IC5* package. If the Q output (pin 5) is at logic one when the strobe pulse appears at the second flip-flop's clock input, a logic 0 appears at pin 8, the second flip-flop's $\overline{Q}$ output. This causes the decimal points on both displays to glow, indicating the overflow condition. The clear pulse then resets the first flip-flop, but the overflow information remains safely stored in the second flip-flop.

The power supply furnishes both a regulated dc voltage and, as mentioned earlier, a full-wave rectified sinusoid which is converted into the time-base waveform. Transformer *T1* and diodes *D2* and *D3* form a full-wave rectifier whose output is applied to switching transistor *Q2* and to filter capacitor *C5*. Diode *D4* isolates the signal driving the base of *Q2* from the filtering effect of *C5*. The stable +5 volts dc required by the TTL integrated circuits is provided by regulator *IC9*. Capacitors *C6* through *C9* shunt any noise on the +5-volt line to ground, and improve the IC regulator's transient response.

Construction of the photo tach is straightforward because circuit layout is not critical. Suitable pc etching and drilling and parts placement guides are shown in Fig. 3. Molex Soldercons or sockets can be used with the IC packages. Be sure to observe pin basing and polarity of all semiconductors and electrolytic capacitors. Mount regulator *IC9* on the project's metallic enclosure for

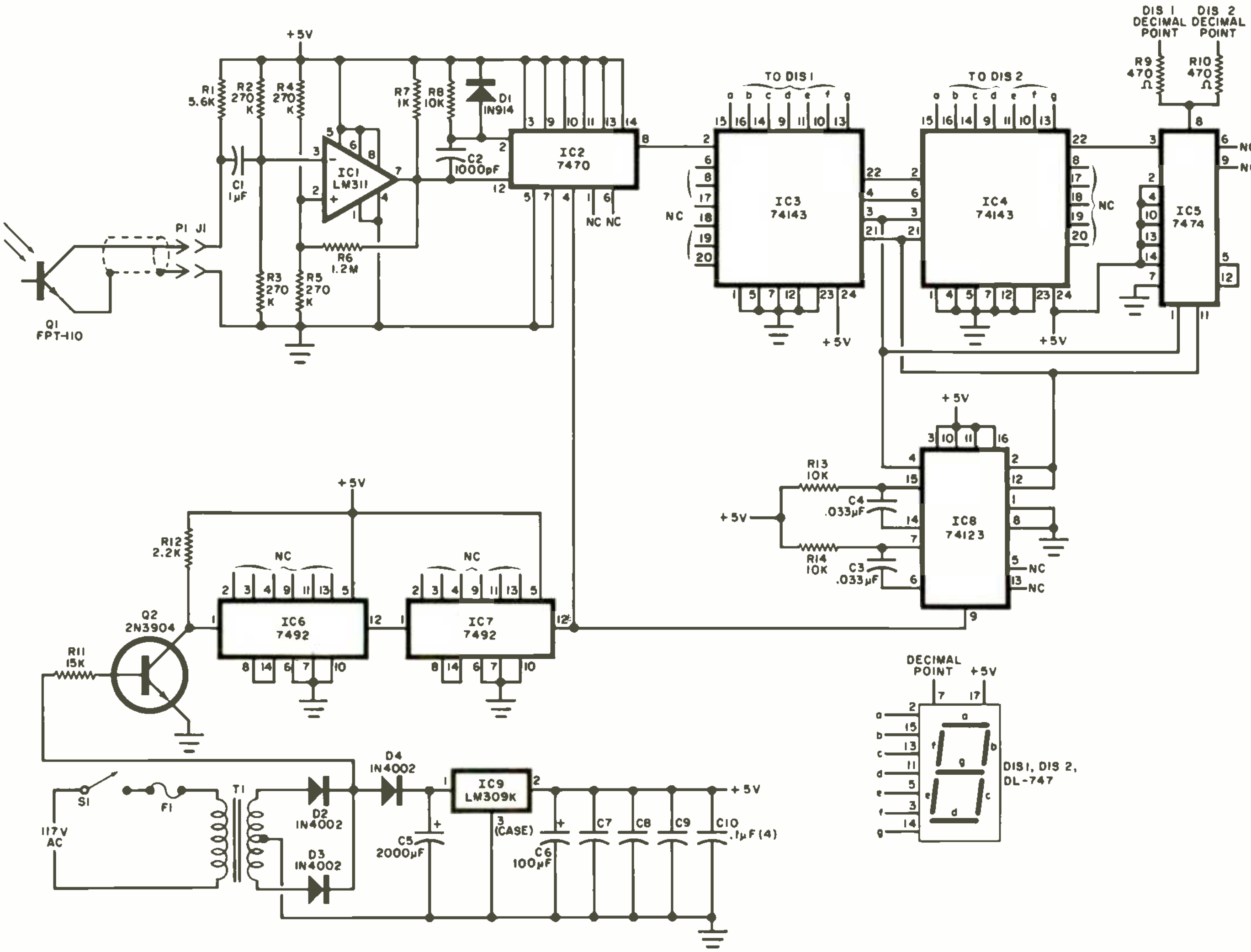


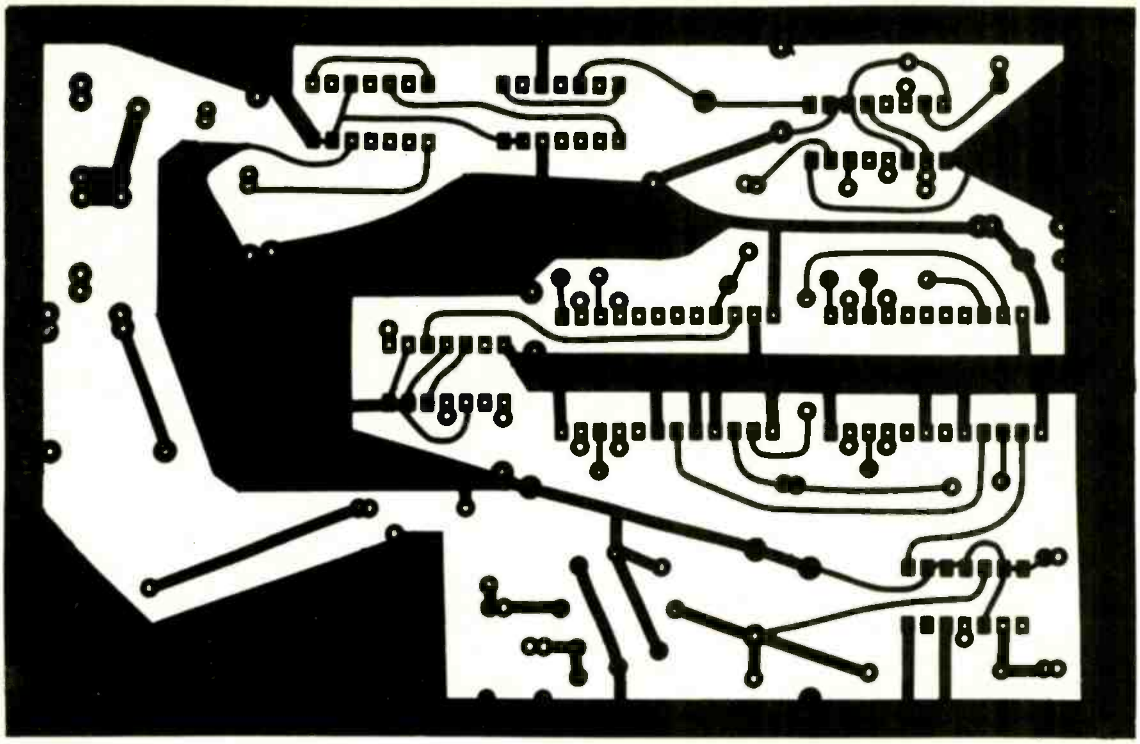
Fig. 2. Schematic diagram shows how pulses from sensor Q1 are squared up by IC1, gated by IC2, and counted by IC3 and IC4.

heat sinking. Spread a thin layer of silicone heat-sink compound on the bottom of the TO-3 can before mounting it. This will ensure a good thermal bond between the IC and the enclosure.

The seven-segment displays should be mounted on a small piece of perforated board installed upright inside the enclosure. Interconnect the displays and integrated circuits with short lengths of hookup wire. Insulated hookup wire should also be used for the eight jumpers on the pc board. The power transformer, switch, and phono jack fuseholder for *F1* are mounted off the board. A probe assembly must be fabricated to house transistor *Q1*. The plastic barrel of a spent ballpoint pen provides a good basis for the probe. Discard the point and exhausted ink tube. Then prepare the phototransistor by clipping its base lead (see Fig. 4). Remove 1" (2.54 cm) of the vinyl jacket from one end of a suitable length of RG-174-U or RG-58-U coaxial cable. Comb out the braid and

PARTS LIST

C1—1-µF Mylar capacitor
C2—1000-pF polystyrene
C3, C4—0.033-µF Mylar
C5—2000-µF, 35-volt electrolytic
C6—100-µF, 16-volt electrolytic
C7, C8, C9, C10—0.1-µF disc ceramic
D1—1N914 signal diode
D2, D3, D4—1N4002 rectifier diode
DIS1, DIS2—DL-747 common-anode, seven-segment LED display
F1—¼-ampere fuse
IC1—LM311 comparator
IC2—7470 J-K flip-flop
IC3, IC4—74143 decade counter/decoder/display driver
IC5—7474 dual-D flip-flop
IC6, IC7—7492 ÷12 counter
IC8—74123 dual monostable multivibrator
IC9—LM309K 5-volt regulator
J1—RCA phono jack
P1—RCA phono plug
Q1—FPT-110 phototransistor (Fairchild)
Q2—2N3904 npn silicon transistor
The following are ½-watt, carbon composition resistors with 10% tolerance unless specified otherwise:
R1—5600 ohms
R2 through R5—270,000 ohms, 5%
R6—1.2 megohms
R7—1000 ohms
R9, R10—470 ohms
R8, R13, R14—10,000 ohms
R11—15,000 ohms
R12—2200 ohms
S1—Spst switch
T1—16-volt center-tapped, 1-ampere transformer (Signal No. 241-5-16)
Misc.—Suitable enclosure, printed circuit board, hookup wire, RG-174-U or RG-58-U coaxial cable, solder, machine hardware, display bezel, etc.
Note—Phototransistor *Q1* is available (No. 22A21011-6) for $1.50 from Burstein-Applebee, 3199 Mercier, Kansas City, MO 64111. Decade counter/decoder/display drivers *IC3* and *IC4* are available for $2.95 (each IC), from James Electronics, 1355 Shoreway Rd., Belmont, CA 94002. Transformer T1 is available from Signal Transformer Co., 500 Bayview Avenue, Inwood, NY 11696 for $7.60. Postage and sales tax (if applicable) extra.



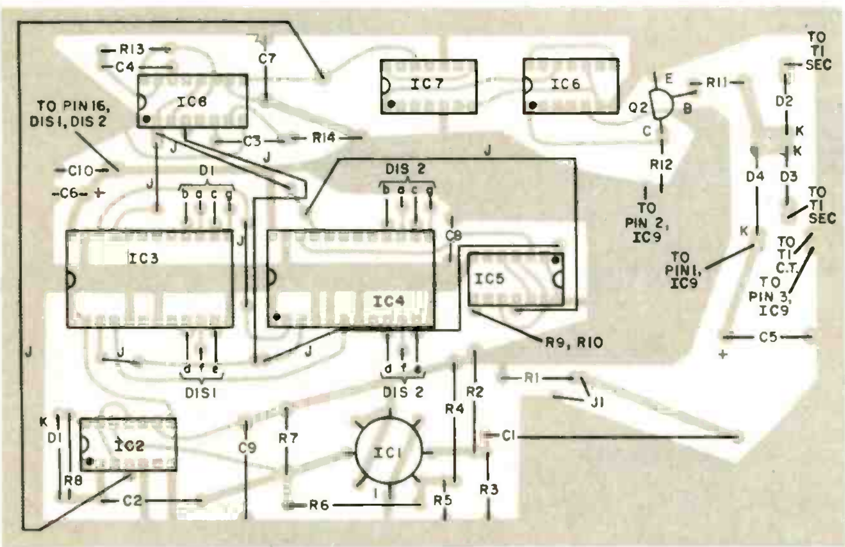


Fig. 3. Full-size etching and drilling guide for pc board is shown above with parts placement guide at left.

twist the strands together. Expose ¼" (6.3 mm) of the inner conductor. Tin the inner conductor and braid with a small amount of solder.

Feed the coax through the pen barrel until the prepared leads extend through the other end. Then attach the inner conductor to the collector of the phototransistor and the braid to the emitter. Pull the coax so that the phototransistor retracts into the barrel, stopping when the light-sensitive surface of *Q1* is recessed about 1" (2.54 cm). Cement or otherwise secure the phototransistor in place, and apply silicone glue where the coax leaves the barrel. Finally, terminate the free end of the cable with an RCA phono plug.

Checkout. No calibration of the photo tach is necessary. With *P1* (the phono plug at the end of the probe cable) removed from *J1*, apply power to the photo tach. Two digits may flash on, but will disappear in about a second. No input pulses are being received, and the outputs of the counters are 0000. Automatic ripple-blanking is built in to the IC counters, so the readouts are darkened and do not display "00."

Apply a 60-Hz, 2-volt p-p sine wave to *J1*. Use either a signal generator or the circuit shown in Fig. 5 as a test source. If the project is functioning properly, "36" will be displayed by the LED readouts. This corresponds to an input of 60 Hz or 3600 rpm.

The operation of the overflow indicator can be verified by either applying a 2-volt p-p sine wave at a frequency of 167 Hz or more, or by optically coupling the probe to an object rotating at 10,000 or more rpm. Both display decimal points will glow, indicating an overflow.

Extending the Range. The photo tach can be modified to measure rotational speeds greater than 9900 rpm by inserting another decade of counting and display between *IC3* and *IC4*. Sever the following connections: pin 22 of *IC3* to pin 2 of *IC4* and pin 4 of *IC3* to pin 6 of *IC4*. Pins 2 and 6 of the additional decade counter should be connected to pins 22 and 4 of *IC3*, respectively. Also, pins 22 and 4 of the additional decade counter should be connected to pins 2 and 6

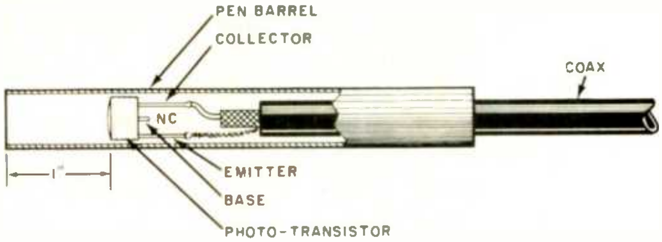


Fig. 4. To make probe, phototransistor is mounted in an old pen barrel and connected to a coaxial cable.

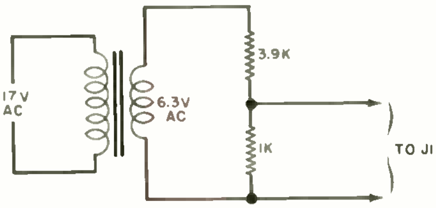


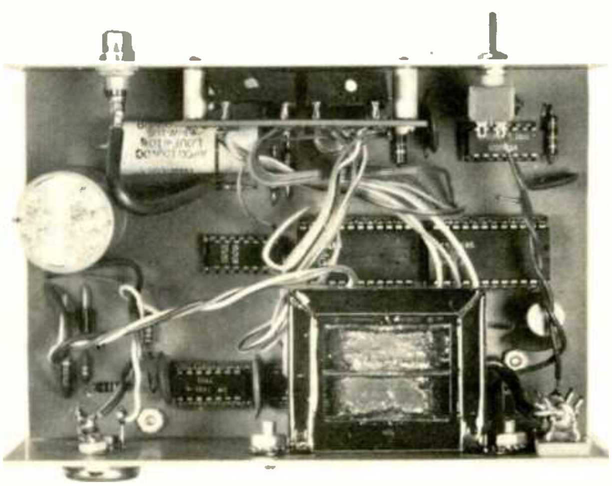
Fig. 5. Schematic diagram of a suitable test source to verify proper circuit operation.

of *IC4*, respectively. Of course, the new counter must be a 74143 IC, and it should be connected to an additional DL-747 display and to the positive supply and ground in the same manner as *IC3* and *IC4*. When this modification has been made, *IC3*'s count will represent hundreds of rpm, the newly installed counter thousands of rpm, and *IC4* tens of thousands. The project's power supply has enough reserve to handle the extra components' demand without any strain.

It is also possible to obtain resolution smaller than hundreds of rpm. If ten light pulses occur during each shaft resolution, the bit significance of each decade of the display is reduced by a factor of ten. Let's consider a specific example. To measure the speed of a slowly turning power drill, a circular disc of metal or plastic should be formed. Ten slots should be punched out at equal intervals along the perimeter and a hole drilled through the center of the disc. Then pass a bolt through the center hole, secure with a nut, and install the entire assembly in the drill's chuck. The rotational speed will then be measured using the transmissive mode and displayed in hundreds and tens of rpm. The addition of another decade of counting and display, as described earlier, can be combined with this multiple triggering technique to display thousands, hundreds, and tens of rpm.

Using the Tach. The optical mode used in a given situation will depend largely on practical considerations. In any event, avoid using fluorescent bulbs as light sources because they are strong electrical noise generators. Ordinary 75- or 100-watt frosted incandescent lamps are well suited for use with the photo tach, as is sunlight. Just remember, however, that if you're checking the speed of a four-blade fan, the actual rate of rotation is one-fourth of what is displayed by the readouts. ◇

Photo of author's prototype shows layout of components in chassis.



NEW, PRACTICAL OP AMP CIRCUITS

BY SOL D. PRENSKY

including a differential pc board tester

AS WE WILL learn from the two very useful circuit applications described here, the operational amplifier (or op amp) can be used in strikingly different ways.

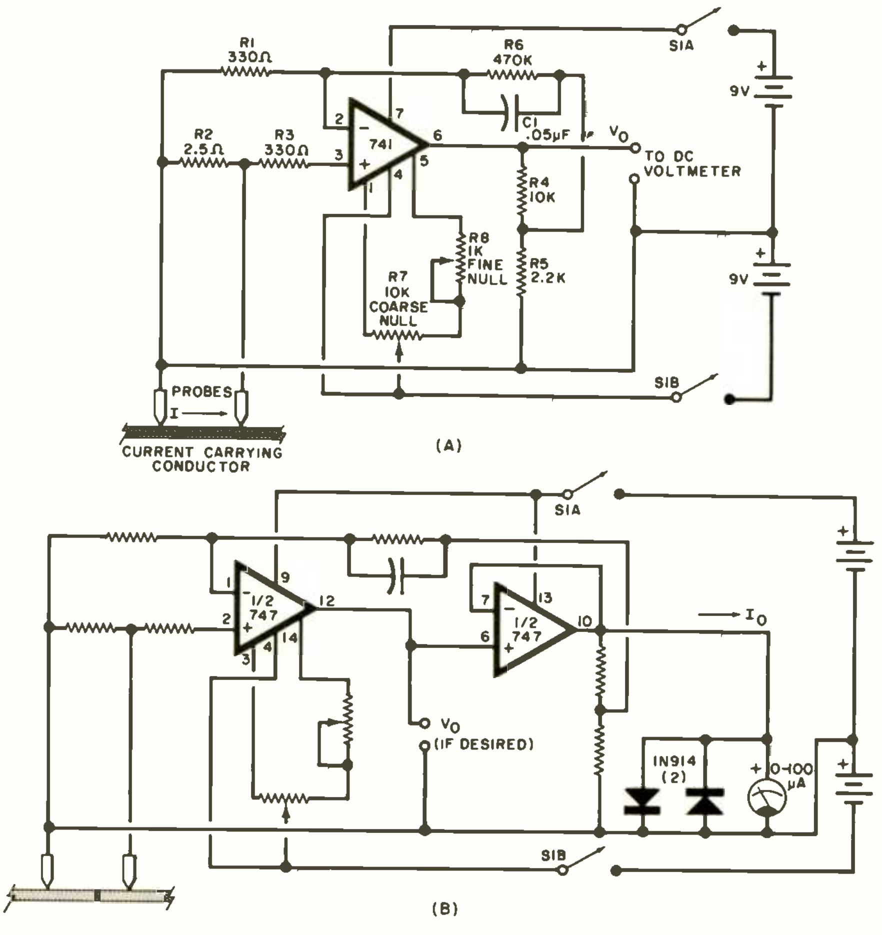
In-Circuit Current Testing. Since an op amp is basically a differential amplifier, it can be used in a unique metering circuit to determine the presence of current flow in a conductor—and approximately the amount of current—whether or not the conductor is a copper wire or a pc foil trace. This can be done without breaking the conductor.

Such a metering device can come in handy if you have a crowded pc board and you suspect one of the active elements (transistor, diode, or IC) is not working. Instead of risking pc board damage due to the heat required to remove the suspect semiconductor, or having to cut a trace to insert a meter, all you have to do is press a couple of sharp probe tips to the copper trace at (for example) the supply bus, and see if that particular element is drawing current, and if the magnitude of the current is within specifications.

The circuit for the current tester is shown in Fig. 1 in two forms—depending on whether you want to use a low-level (1-volt) dc voltmeter or a current meter as the readout.

Operation is based on the fact that at room temperatures, all conductors have

Fig. 1. Op amp in (A) measures slight voltage differential between two probes, amplifies it, and drives dc voltmeter. Addition of another op amp in (B) permits driving ammeter.



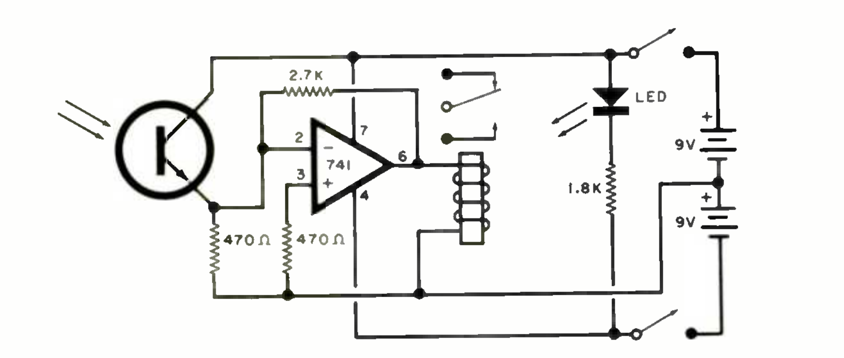


Fig. 2. Phototransistor and op amp unite to form light-sensitive relay driver that can be activated by a flashlight across the room.

some resistance (albeit small) and, when current flows through the conductor, there is a slight voltage drop between any two points along the conductor. Typically, such voltage drops are in the microvolt range; but with a voltage amplifier having a gain of 1000 or more, the minute voltage can be brought up to a reasonably measurable value.

The basic circuit shown in Fig. 1A uses an 8-pin mini DIP 741 with a dc voltmeter. This circuit takes advantage of the high common-mode rejection ratio (CMRR) of the op amp to reject any noise pickup voltages that are common to both input terminals. To keep the value of feedback resistor *R6* to a reasonable value, the output of the op amp (pin 6) drives the combination of *R4* and *R5* with the feedback taken from the junction of these two resistors. This voltage divider action in the feedback voltage multiplies the conventional gain (1 + *R6/R1*) by the voltage divider ratio (*R4* + *R5*)/*R5* to produce a theoretical voltage gain of approximately 1400 times 5.5 or 7700.

Since any residual offset voltage generated within the op amp is also multiplied by this factor, two offset (coarse and fine) potentiometers (*R7* and *R8*) are provided to trim the offset close to zero with the input probes shorted.

Figure 1B uses a 747 dual op amp package to drive a 100-μA meter that is used as the readout. Two diodes are used to protect the meter from accidental overloads. Operation of the circuit is otherwise the same as that of Fig. 1A.

In experiments with these circuits, probing a current-carrying conductor produced "ball-park" figures of 12 mV/inch or 12 μA/inch, for each milliampere of current flow. In general, it would be too much to expect either precision or close calibration results from such a general-purpose circuit as opposed to a specialized (and expensive) instrumentation amplifier. Nevertheless, the circuits of Fig. 1 do indicate current flow in a conductor and can be reasonably calibrated. For improved stability, a premium op amp such as Precision Monolithics OP2, National LF156, etc., may be used. Where currents greater than approximately 1.5-mA are concerned, the sensitivity of the circuit can be reduced by lowering the value of feedback resistor *R6*.

Photo Switch. The circuit shown in Fig. 2 illustrates how an op amp, in conjunction with a phototransistor and relay, can be used to activate a relay with a conventional flashlight used as the remote "transmitter." With the relay connected across the speaker coil leads, this circuit makes an excellent "commercial killer." The op amp's pinout is for an 8-pin mini DIP.

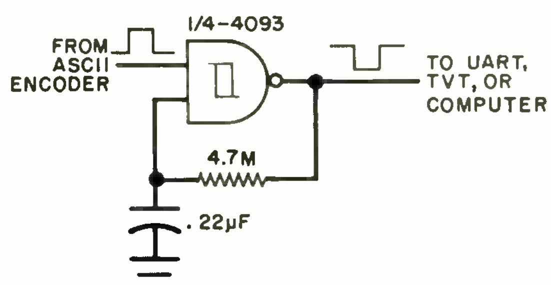
The phototransistor is connected to the op amp to produce an inverter amplifier gain of about 50. For most "across the room" distances, using a typical flashlight, the output of the op amp will be sufficient to energize a sensitive relay. (A Sprague 401-A050-A05 requires about 6 mA at 3 volts, for example.) If any other type of relay is to be used, keep in mind that the op amp can deliver only about 10 mA at best, so if higher currents are required, a transistor relay driver must be used.

Although almost any type of sensitive phototransistor can be used, the prototype involved half of an opto-isolator (LED and phototransistor in one package) that had been sawed in half. In these units, the phototransistor sensitive area is protected from ambient light by a built-in IR filter so that the quiescent current before flashlight illumination is practically negligible. The LED power-on indicator requires about 10 milliamperes for operation and may be eliminated if it is not required. ◇

SIX CMOS CIRCUITS FOR EXPERIMENTERS

Using CMOS digital integrated circuits can simplify designs, cut costs, and reduce power supply requirements. Here are six basic examples of how the use of CMOS can "do more for less"—circuits every experimenter should have in his bag of tricks.

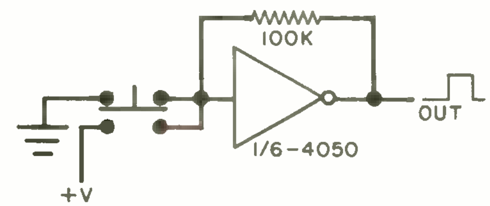
BY DON LANCASTER



Automatic Keyboard Repeat

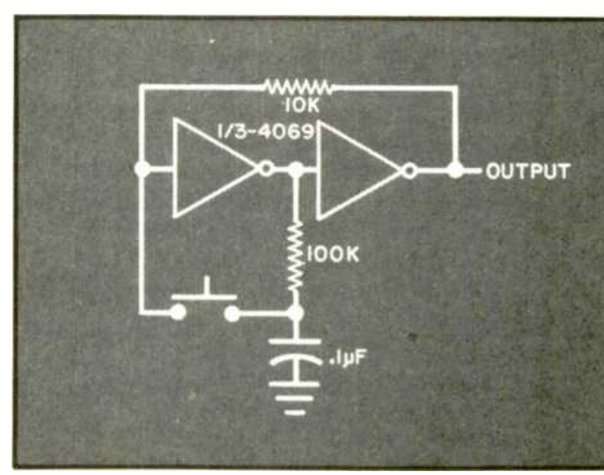
1 This circuit can be added to almost any ASCII keyboard and encoder to create a simple, low-cost repeat function. The circuit shown uses the positive output of a 2376 keyboard encoder IC to drive the negative-going input required by many UART's and TVT's.

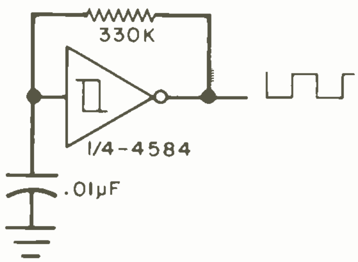
The signal from the keyboard encoder is normally low, thus this circuit has a high output. When a key is depressed, the positive-going pulse from the encoder drives this circuit output low for as long as the key is depressed. However, if the key is held down, the circuit will deliver outputs that repeat as long as you want. This is handy for cursor motions, adding spaces, etc. A one-second delay is provided between the first and second output pulses, and after that, the pulses will be repeated at a three-per-second rate. This built-in delay is created by the longer initial charging time of the capacitor, followed by the faster motion between the Schmitt trigger upper and lower trip points. You can use the other NAND triggers in the package to shorten pulses, or invert input or output.



Contact Debouncer

2 Pushbuttons and switch contacts must be debounced when used with clocked logic. Otherwise, contact noise and bounce will produce multiple "hits". The feedback resistor in this noninverting buffer circuit will hold the output in either the high or low state. The spdt pushbutton forces the circuit into one state or the other, while the latching holds the circuit in that state, during the debounce interval. Actually, the resistor can be eliminated and replaced with a short between the input and output, but this may add some current "glitches" to the power supply line. Six switches may be conditioned using the six buffers in the IC package.





Square-Wave Generator

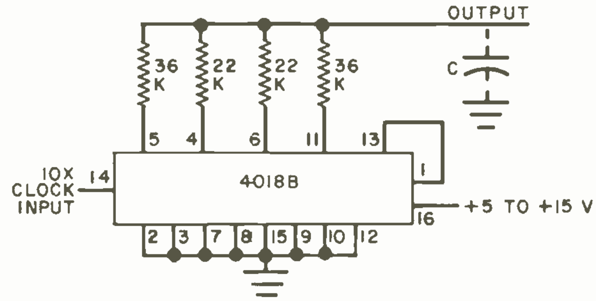
3 With the values shown, this circuit generates approximate 1-kHz square waves. When the Schmitt trigger output is high, the capacitor charges to the supply voltage through the resistor. When the voltage across the capacitor reaches the upper trip point of the Schmitt, the output drops low. The capacitor then discharges through the resistor, and when the capacitor voltage reaches the lower trip point, the Schmitt output snaps high and the cycle repeats.

The circuit is sure starting, and the output swings the full power supply level which can be anything between 5 and 15 volts. Supply current is typically 10 microamperes. Since the capacitor voltage always remains between the two trip points, no input protection is required. The frequency can be altered by selection of the resistor and/or capacitor value.

Alternate Action Pushbutton

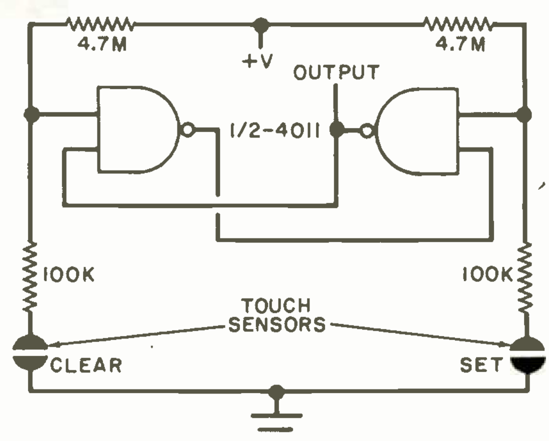
4 Each time the pushbutton switch is operated, the circuit shown here changes its output state. On one depression, the output is high; and on the next depression, the output is low. Operation is reliable and the pushbutton is fully debounced.

Despite its apparent simplicity, this is a full-fledged master-slave flip-flop with the RC network being the "master" that remembers where the output is to go. The two inverters form the "slave" latch.



Digital Sine-Wave Generator

5 This circuit uses a clock frequency 10 times the required output frequency. The walking-ring counter and resistor summing network will produce a "chunky" waveform at the output. However, you can filter this waveform since it is basically a sine wave with a little of the 9th and 11th harmonics present. You can either ignore the harmonics or use a capacitor (shown dotted on the schematic) as a filter. If desired, an active filter can be used. The unfiltered output swings the full supply voltage which can range from 3 to 15 volts.



Touch-Controlled Latch

Short the SET contacts with your fingertip and the output goes high. Later on, if you touch the CLEAR contacts, the output goes low. In this simple set-reset flip-flop, the 4.7-megohm resistors hold the NAND gates inputs high, and are disabled when the 200,000 ohms or so of finger resistance provides the "low impedance" path to ground, to force the circuit to change states.

The touch sensors may be any type of conductive material with a slight gap between the two elements.

ACCURATE MILLIAMMETERS ON A BUDGET

How to modify surplus-type meters to obtain high accuracy.

BY DAVID CORBIN

Buying an ammeter with built-in shunts to measure currents from milliamperes to hundreds of amperes can be an expensive proposition. It is much less costly to obtain a basic 1-mA movement and add the shunts you need to create the necessary ranges. This can be done by using the table supplied here. It tells you what shunt values are required for a given milliammeter movement with a 1-mA full-scale swing.

About Accuracy. Depending on the movement you choose and how much you pay for it, basic accuracy will be between 1% and 5% full-scale. The accuracy figure is loosely based on both repeatability and scale precision. Bear in mind that the accuracy of large panel meters is generally no better than 1% full-scale. What these movements offer for the high prices they command are ruggedness, long life, temperature compensation, magnetic shielding, and high breakdown voltage, all of which may be important in some applications. Where the application is not critical, you can choose a small \$3.50 to \$6.00 panel meter and get more than adequate results.

When you look at accuracy figures for basic meter movements, be sure you understand the meaning of the figures. Since a current-measuring meter is placed in series with the source and load, it should have the lowest possible resistance for maximum sensitivity. The meter's resistance is a part of the circuit and affects the overall flow of current.

Let us assume that you have two meters, one with a 50-ohm resistance and the other with a 100-ohm resistance. If you were to insert the 100-ohm meter into a circuit with 100 ohms resistance in which the actual current flow is 1 mA, the meter would indicate 0.5 mA. Substituting the 50-ohm meter would yield a 0.67-mA reading. The readings obtained are the actual currents flowing in the circuit *while the meters are in the circuit* and they are within 1% of the actual current. (Of course, if you remove the meters, the current in the circuit would again become 1 mA.) The discrepancies are the result of the fact that the meters add their own resistance to the circuit and reduce the overall current flow.

If the meters had zero resistance (impossible to achieve in practice), they would not affect the flow of current. In this case, both meters would indicate 1 mA. It is obvious then that, in the world of real measurements, you must take into account the effect the meter has on the circuit that is being tested.

Custom Tailoring. Since the voltage it takes to swing the milliammeter's pointer to full-scale is the product of full-scale current times coil resistance, it is easy to design circuits and make reference charts for choosing shunt and series-shunt combinations. It is amazing how small a voltage is required for a full-scale pointer swing on a typical 1-mA movement. For example, a 50-ohm, 1-mA movement requires 1 mA × 50 ohms, or 50 mV (0.050 V) full-scale.

The problem is that many low-cost meter movements are provided with no specifications other than the scale markings. You cannot measure the coil resistance with an ohmmeter because the test voltage is much too high and can damage the movement or burn out the meter's coil. The best way to check milliammeter movements is with a simple meter calibration circuit like that shown in Fig. 1. For this, you will need a good standard multimeter capable of indicating current to 1 mA full-scale. (Even a \$6 basic movement will do if its coil resistance is specified.)

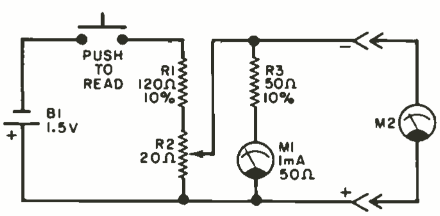


Fig. 1. Here is a simple meter calibration circuit you can use to check meter movements.

The meter calibrator shown in Fig. 1 uses a 50-ohm movement. This movement indicates half of the voltage dropped across tested movement *M1*. The total reading from *M2* is read as 0 to 0.1 volt or as 0 to 100 ohms. Potentiometer *R2* is adjusted for a full-scale reading on *M1*.

Once you know coil resistance R_M and full-scale voltage E_M, as indicated on *M2*, you can calculate the shunts needed to increase the basic movement's range. The formula for this is $R_S = E_M/(I_D - I_M)$ where R_S is the shunt resistance in ohms and I_D and I_M are the design and movement's full-scale currents in amperes. However, to avoid having to perform the mathematics, you can refer instead to the table, which gives the values of the shunt resistors needed for various 1-mA meter movements for a variety of full-scale ranges. The resistances in the table are rounded off to three places in most cases. It isn't necessary to be too accurate in shunt-resistor selection because of the limitations resulting from the built-in errors of the basic meter movement itself.

About the best possible accuracy you will be able to obtain, no matter how precise the values of the shunt resistors, will be 1% of the full-scale reading. The resistors you use will not normally be better than 1% to 5%, and the meter movement itself cannot be interpreted to better than 1% accuracy even if it is the best available.

The 1-mA movement will probably be calibrated in 10 major divisions, with five minor divisions between each. This works out to 0.1-mA major and 0.02-mA minor steps when only the basic measuring range of the movement is considered. When multiplied by the shunt factor for a 50-mA full-scale reading, the major steps are each 5 mA and the minor steps are each 1 mA. However, without an antiparallax mirror backing on the movement and other refinements, one minor division is about the limit of what you can interpret on any reading.

Thus, a 1-mA error is possible in the reading and 0.5 mA in the meter's basic accuracy. In terms of a shunt, assuming a 50-ohm movement, this is like using a 1-ohm resistor instead of the required 1.02 ohms. In fact, the difference of 0.5 mA caused by the movement itself would be the same as an error of from 1.0098884 to 1.0309278 ohms instead of the exact 1.0204081 ohms required.

SHUNTS NEEDED FOR VARIOUS MOVEMENT RESISTANCES AND FULL-SCALE CURRENT

	Shunt (ohms)				
Movement (ohms) **Current** (mA)	12.5	25	50	75	100
5	3.13	6.25	12.5	18.75	25.0
10	1.39	2.78	5.56	8.33	11.1
25	0.52	1.04	2.08	3.13	4.17
50	0.26	0.51	1.02	1.53	2.04
75	0.17	0.34	0.68	1.01	1.35
100	0.13	0.25	0.51	0.76	1.01
150	0.08	0.17	0.34	0.50	0.67
200	0.06	0.13	0.25	0.38	0.50
500	0.025	0.05	0.10	0.15	0.20
1000	0.0125	0.025	0.05	0.075	0.10
10,000	0.00125	0.0025	0.005	0.0075	0.01

This simply points out the limit of accuracy to be expected with *any* moving-coil type of meter. Needless to say, the home-built metering circuit can be as accurate as the best commercial analog meters.

To avoid having to wind special resistors, you can use combinations of standard resistor values to make the required shunts because the precision required for good results will not be excessive. The formula for determining the value of the parallel resistor needed for a given shunt value and given one resistor of known value is $R_U = R_S R_K/(R_K - R_S)$, where R_U is the resistance to be found, R_S is the desired shunt resistance, and R_K is the value of the known resistor. To obtain a good many values with odd decimal endings, a fractional value resistor can be used in series with a standard larger value resistor. Of course, the accuracy will suffer when the possible errors of the resistor values are added to the circuit. However, if you use 1% and 5% tolerance resistors and the scale multiplication is large, the amount of overall error will be in the same range as the limits of the meter movement itself and will not have much effect on the accuracy of the reading.

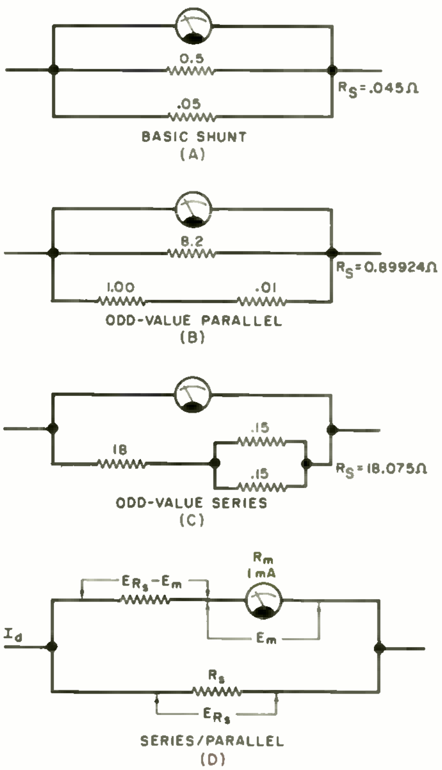


Fig. 2. Various configurations for using shunts with meters.

The power that is generated in the shunt must be handled without excessive heating of the shunt or the values of the shunt resistors will change. By using resistors with 50% greater heat dissipation (power rating) than is actually required, you will not exceed safe limits. Even with a 10-ampere shunt, the current is not large enough to generate much heat in a 0.01-ohm load. The power generated will be 1 watt, so a 2-watt resistor will be more than adequate. Smaller currents develop correspondingly lower power in the shunts. The formula for calculating the power rating of the shunt resistors is $P = 1.5E_M\,(I_D - 0.001)$, where P is the power in watts, E_M is full-scale meter voltage in volts, and 0.001 is the value of the 1-mA meter movement's full-scale current.

To measure higher currents without having to resort to very small values of resistors and resistor combinations for the shunts, a dropping resistor can be placed in series with the meter movement. (Various configurations of shunt circuits are shown in Fig. 2. The Fig. 2D circuit illustrates the resistor placed in series with the meter movement.) If you know the value required for shunt resistor R_S, the formula for determining the value of dropping resistor R_D is $R_D = [R_S(I_D - 0.001) - E_M]/0.001$, where R_D is in ohms, I_D is in amperes, and 0.001 is the full-range current of the meter movement. To find R_S when the total drop is specified, use the formula $R_S = E_{RS} / (I_D - 0.001)$. Then $R_D = (E_{RS} - E_M)/0.001$.

The Fig. 2D circuit can be used when a certain voltage drop is required in a metering circuit and it is different from the drop that would result from using a standard shunt circuit. It is also handy for avoiding small values of resistance, but the pitfall is excessive power loss through the shunt when measuring high currents.

The power in the shunt is calculated by subtracting 1 mA from the design current (I_D) and multiplying this times the voltage drop across the shunt, which is the same as the total circuit drop. Almost any value of resistance can be used for the shunt, but the power rating will go up in direct proportion to the resistance for any given current measurement. The biggest advantage will be in the avoidance of odd-value shunt resistors that cannot readily be obtained by connecting resistors in parallel or series-parallel configurations.

Multirange general-purpose meters can be made by using a combination of simple shunt and series-shunt networks and a multi-position switch. The lower ranges, where shunts are obtainable in close-to-standard values, can have the shunts switched directly across the meter movement.

Summing Up. The design of current-measuring circuits in which a standard 1-mA meter movement is used is applicable to even the most limited budget and available test equipment. It provides accurate current monitoring in up to four decade ranges at a typical cost of less than $15. A single-value monitor circuit can be installed in a project for less than $9, and it will provide an accuracy of between 1% and 5% full-scale, depending on the care taken during the design stages. The problem of finding and stocking a variety of current meters is solved by keeping one or two milliammeter movements handy and making up a few standard shunt circuits to use with them as described here. ◇

BY GENE NELSON

AUDIO ALARM BACKS UP CAR WARNING LIGHTS OR METERS

Easy-to-build circuit sounds an alarm so you won't miss your car's visual warning.

PEOPLE often fail to notice immediately when a red indicator on the dashboard of a car lights to warn that service is required. The "Audible Car Protection Alarm" described here corrects this problem by simultaneously issuing an audio signal when a dashboard warning indicator is activated. It can spell the difference between a minor and a major car repair, or even save lives.

When any one or more of the warning indicators in your vehicle lights, the audio alarm sounds an insistent beeper. Then you can check the indicators to determine what service is required.

In addition to serving as an automatic fault monitor, the alarm can also remind you to turn off headlights and rear-window defogger. The system can easily be expanded to monitor dozens of points in a vehicle's or boat's electrical system.

About the Circuit. As shown in Fig. 1, triple three-input NAND gate *IC1* serves three separate functions. Section A operates as a conventional three-input NAND gate. If one or more of its normally high A, B, and C inputs goes low, the pin-10 output of this gate also goes high.

Section B, also used as a three-input NAND gate, has a 1500-Hz signal applied to its pin-2 input, a 1-Hz signal applied to its pin-1 input, and the output from section A of *IC1* applied to its pin-8 input. Hence, when the output from section A goes high, the circuit oscillates at 1500 Hz and is gated on and off at approximately half-second intervals.

Section C of *IC1* is configured as an inverting amplifier whose output is coupled back to its input via *R1* and oscillates at a frequency determined by the values of *R1* and *C1*.

The output of section B drives *Q1*, whose collector load is a conventional miniature 8-ohm loudspeaker. The combination of *C3*, *R2*, and *R3* functions as the system's 1-Hz oscillator. Capacitor *C3* charges through *R2* and discharges through *R3*. This capacitor must be initially charged before the circuit can os-

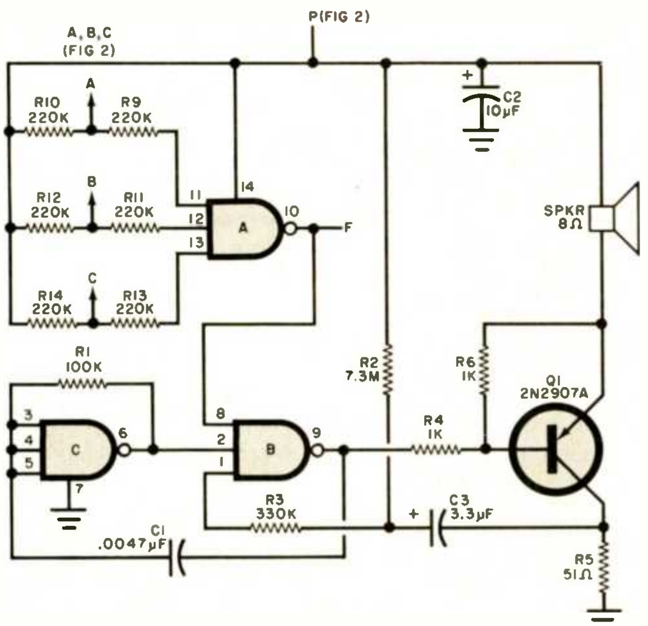


Fig. 1 Gates IC1C, IC1B, and Q1 form a 1500-Hz oscillator gated on and off by a 1-Hz signal.

PARTS LIST

C1—0.0047-µF Mylar
C2—10-µF, 16-volt electrolytic
C3—3.3-µF, 25-volt tantalum
D1 through D5—1N4148 or similar silicon diode
IC1—CD4023AE (RCA) CMOS triple three input NAND gate
LED1—Red light emitting diode
Q1—2N2907A or similar pnp transistor
The following resistors are ¼-watt, 10%:
R1—100,000 ohms
R2—5.1 and 2.2 megohms in series
R3—330,000 ohms
R4,R6,R15—1000 ohms
R5—51 ohms
R7—22 ohms
R8—2200 ohms
R9 through R14—220,000 ohms
SPKR—8-ohm, 100-mW loudspeaker
Misc.—14-pin DIP socket; plastic case; printed circuit or Wire Wrap board; splice-in connectors; hookup wire; solder; machine hardware; etc.

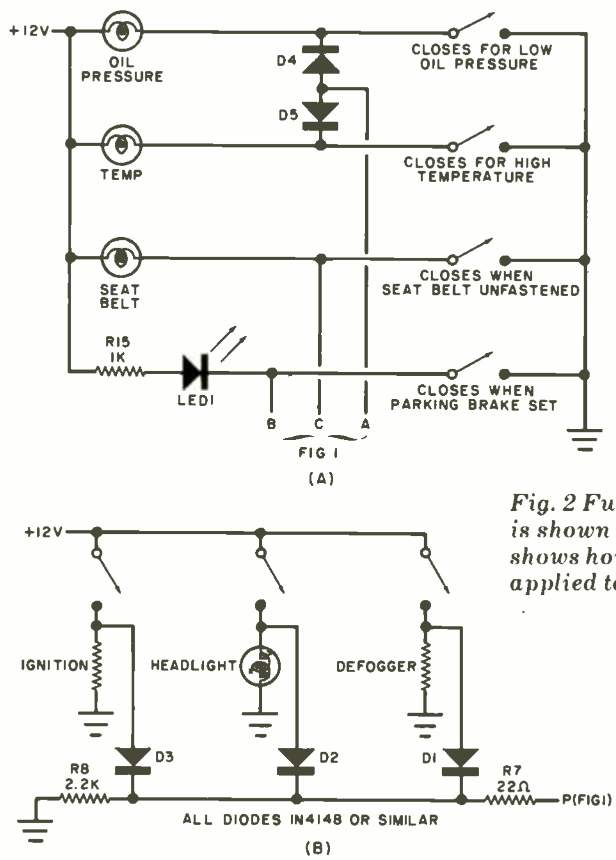


Fig. 2 Function sensing is shown at (A) while (B) shows how dc power is applied to the alarm circuit.

cillate. With the value shown for *C3*, a delay of about 15 seconds is provided before the alarm enables. This allows time for normal engine starting and the build-up of oil pressure. Consequently, during normal operation, the alarm will not sound.

To see how the circuit operates under actual in-use conditions, let us assume that the oil pressure drops. As shown in Fig. 2A, the oil-pressure sender grounds the oil-pressure lamp, which then comes on. Simultaneously, the cathode of *D4* is placed at ground potential. At this point, *D4* conducts through *R10* and pin 11 of *IC1A* goes low, causing the output of this gate to go high. As long as *C3* is charged, *IC1A* allows the 1500-Hz oscillator to operate. When the potential across *C3* reduces sufficiently, the oscillator ceases operating until *C3* recharges. Therefore, the 1500-Hz oscillator is gated on and off by the *R2, R3, C3* circuit at 0.5-second intervals. The beeping of the alarm continues until all of the circuit's A, B, or C inputs are ungrounded.

In Fig. 2B, diodes *D1* through *D3* are connected to the ignition, headlights, and defogger (if any) circuits so that when any of these switches is closed, the associated diode is forward biased and conducts to apply power to the alert circuit via *R7* and its associated *C2* filter capacitor.

As an example of the foregoing, assume that the ignition is turned off, but either the headlights or the defogger is left on. The alarm will then receive power through the diode attached to the headlight or defogger switch, thereby sounding off and continuing to do so until the headlight or defogger switch is turned off. This is because when the engine is turned off, the oil pressure drops to close its sensor switch, thus activating the alarm. This action will also occur even if the oil-pressure lamp is burnt out, since the A input will still be grounded. The rear window defogger is also included since in many cars, this accessory will still operate when the ignition is turned off.

Construction. The simple circuit that makes up the system can be wired by any convenient means, including a printed circuit board, Wire Wrap, and point-to-point. Since there are no high frequencies with which to contend, lead dress is not critical.

The alarm can be mounted in any box that will accommodate it and the speaker. A barrier strip, mounted on the enclosure, can then be used to make all power, ground, and sensor connections.

The diode coupling technique shown in Fig. 2A can be used to increase the number of sensing points to monitor other elements in a mobile system. Each NAND-gate input can handle a large number of inputs, connected in parallel.

Note in Fig. 2A how a LED parking brake set circuit can be added to the alarm circuit. The switch associated with this sensor can be a conventional microswitch mounted so that, when the parking brake is set, the switch closes. The LED can be mounted on the dashboard and suitably identified.

Installing the System. Before the alarm is installed in a vehicle, it should be tested for proper operation. Connect a 9-volt battery between the ignition input and ground. Temporarily connect sensor input A to ground. After about 15 seconds, the alarm should begin to beep. Disconnect the sensor input from ground; the alarm should cease beeping. Repeat this procedure with sensor inputs B and C. The positive terminal of the battery can be connected with a jumper wire to the headlight and defogger inputs to test the operation of these functions.

Make all connections to the various points in the vehicle's electrical system securely and with care, preferably with splice-in connectors where possible. If you use a strip-and-wrap splice, make sure you cover each connection with vinyl electrical tape.

Dress all wires to protect them from mechanical and heat damage. Do *not* connect the ignition input to the ignition coil; otherwise, it may be damaged by transients from the coil. It goes to some accessory that is powered only when the ignition switch is turned on. Make sure that the headlight and defogger input power connections are made as shown in Fig. 2B.

After installation is complete, turn on the ignition but do not start the engine. (Set the ignition switch to the ON position only.) Since the low-oil pressure switch will be closed, after the delay period, the alarm should begin to beep. Turn on the headlights and turn off the ignition. The alarm should continue to beep and stop only when you switch off the headlights.

The alarm circuit can be used for monitoring other dc electrical systems. If failure modes are indicated by a "high" voltage, these can be diode OR'ed at input F (see Fig. 1) with the output of *IC1A*. ◇

BY RAY WILKINS

FOUR EASY-TO-BUILD LED PROJECTS

WITH THE prices of LED's and CMOS IC's continuing to drop, electronics experimenters should take advantage of the circumstances and build some of the many interesting projects that can be made using these devices. The four circuits described in this article are not only fun to build, they also teach the builder quite a bit about the devices and their uses.

The circuits take advantage of the fact that CMOS devices require very low power, so no power on/off switches are used. The quiescent current drawn by the CMOS chips (when the LED's are off), allows normal battery shelf life. Once the pushbutton switch on a project is operated, the circuit "does its thing," and then stops.

Blinker. As shown in Fig. 1, this circuit uses a single CMOS hex inverter to provide both timing and drive to make the two LED's blink alternately. Built with two small red LED's, the circuit makes

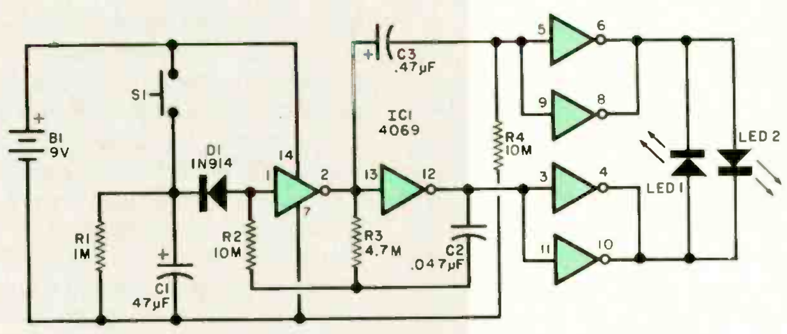


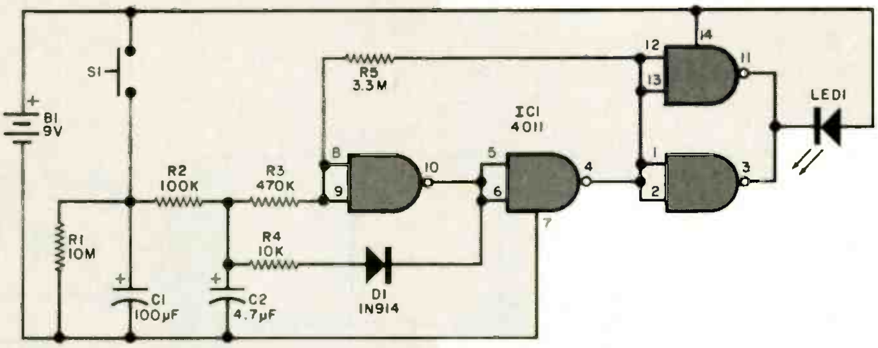
Fig. 1. Dual LED alternate blinker uses parallel gate output for more LED driving current.

BLINKER PARTS LIST

B1—9-volt battery
C1—47-µF, 10-V electrolytic
C2—0.047-µF disc capacitor
C3—0.47µF, 10-V electrolytic
D1—1N914 diode
IC1—4069 CMOS hex inverter
LED1, LED2—Light emitting diode (2 red, or 1 red/1 green)
R1—1-megohm resistor
R2, R4—10-megohm resistor
R3—4.7-megohm resistor
S1—Normally open pushbutton switch

an ideal HO-gauge model railroad crossing blinker. With LED's of two different colors (in one package), it can be used to obtain other effects.

Resistors *R2* and *R3* and capacitor *C2* determine the flash rate, while *R1* and *C1* set the total display time. The component values shown here produce a blinking rate of two per second and an on time of about 20 seconds. To change the timing, change the values of the capacitors since decreasing the value of the resistors will increase the quiescent battery current drain.



FLASHER PARTS LIST

B1—9-volt battery
C1—100-µF, 10-V electrolytic
C2—4.7-µF, 10-V electrolytic
D1—1N914 diode
IC1—4011 CMOS quad 2-input NAND gate
LED1—Red light emitting diode
R1—10-megohm resistor
R2—100,000-ohm resistor
R3—470,000-ohm resistor
R4—10,000-ohm resistor
R5—3.3-megohm resistor
S1—Normally open pushbutton switch

Fig. 2. Single LED flasher also uses parallel gate output for driving the LED.

Flasher. A simple variable-rate LED flasher is shown in Fig. 2. The voltage across *C1* determines the flash rate. When the pushbutton switch is closed, capacitor *C1* charges to 9 volts and the flasher blinks rapidly. As the voltage is discharged through *R1*, the flasher slows down until the charge on *C1* reaches about 4.5 volts, at which point the oscillator stops and the LED stays off. The flash rate is set by the values of *R2*, *R3*, *R4*, *R5*, and *C2*. Capacitor *C1* and bleeder resistor *R1* create the slow-down period.

Binary Counter. A circuit that demonstrates the operation of a six-bit binary counter is shown in Fig. 3. When the

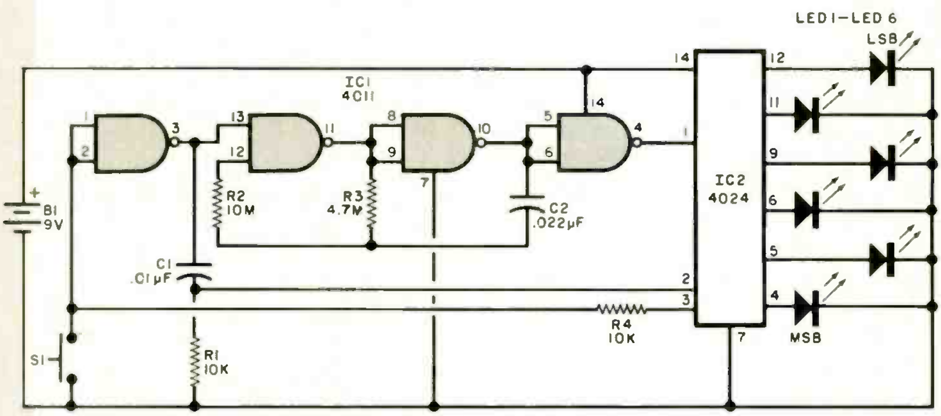


Fig. 3. Simple binary counter illustrates counting in the 1-2-4-8-16-32 mode.

BINARY COUNTER PARTS LIST

B1—9-volt battery
C1—0.01-µF disc capacitor
C2—0.022-µF disc capacitor
IC1—4011 CMOS quad 2-input NAND gate
IC2—4024 CMOS binary counter
LED1-LED6—Red light emitting diode
R1, R4—10,000-ohm resistor
R2—10-megohm resistor
R3—4.7-megohm resistor
S1—Normally open pushbutton switch

pushbutton switch is depressed, the circuit starts counting from zero (all LED's off) to 63 (all LED's lit). After reaching the full count, the circuit automatically resets to zero and shuts itself off. The six LED's come on in a binary (1, 2, 4, 8, 16, 32) sequence which is typical of digital counters.

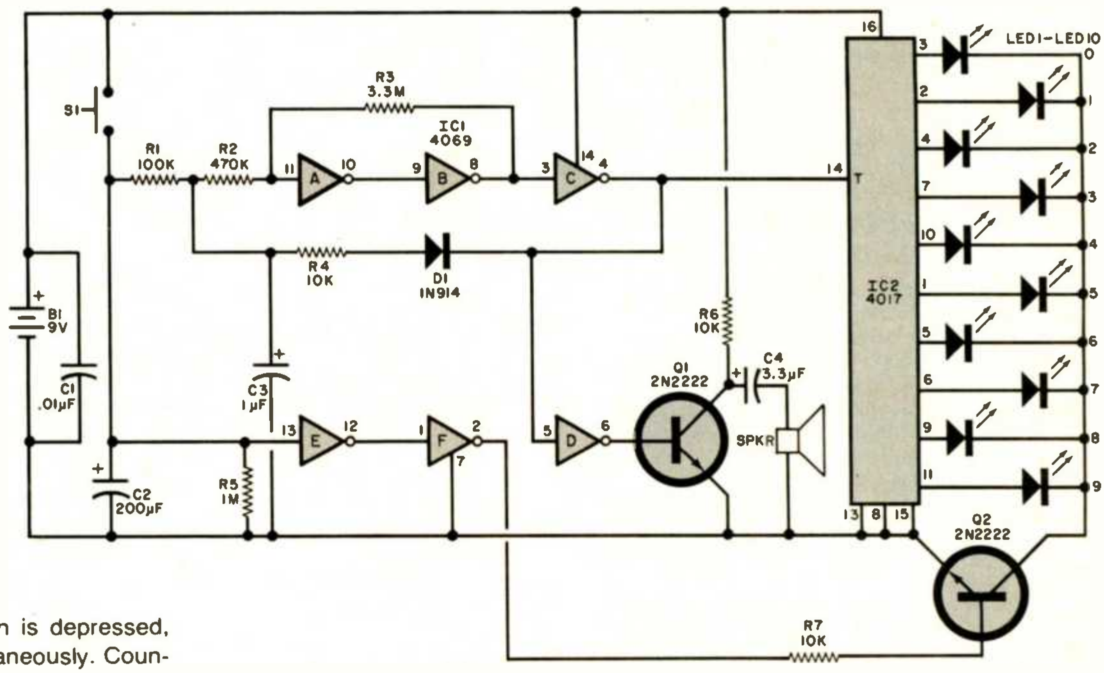


Fig. 4. "Wheel of Fortune" sequentially lights one of 10 LED's and generates audible clicks.

When the pushbutton is depressed, two things occur simultaneously. Counter *IC2* is reset to zero by the signal on pin 2, thus placing all of the *IC2* outputs at their low states (0 volt). Thus, none of the LED's can glow. The second action is an enable level signal (+9 volts) at pin 13 of *IC1*. This action allows the oscillator (the middle two gates) to start, thus producing an input signal to the counter IC through the last gate of *IC1*.

The counter then counts until it is full, illuminating the LED's in the proper sequence. One count after full count is reached, pin 3 of *IC2* goes high. This signal is inverted by the first gate of *IC1*, and its output goes low, thus disabling the oscillator. The circuit then remains in the "all LED's off" state until the pushbutton is depressed again. The value of *C2* can be changed to increase or decrease the counting speed.

Wheel of Fortune. The circuit shown in Fig. 4 is a 10-LED spinning wheel with audible 'clicks' as the wheel passes each point. The rotation starts fast, then gradually slows down to a random stop (with a click at each position). After the rotation ceases, the selected LED stays lit for about 10 seconds, then goes out. The cycle restarts by depressing the pushbutton switch.

The logic requires only two IC's. Of these, *IC1A*, *IC1B* and *IC1C* form a vari-

WHEEL OF FORTUNE PARTS LIST

B1—9-volt battery
C1—0.01-µF disc capacitor
C2—200-µF, 10-V electrolytic
C3—1-µF, 10-V electrolytic
C4—3.3-µF, 10-V electrolytic
D1—1N914 diode
IC1—4069 CMOS hex inverter
IC2-4017 CMOS decade counter decoder
LED1-LED10—Red light emitting diode
Q1, Q2—2N2222 transistor
R1—100,000-ohm resistor
R2—470,000-ohm resistor
R3—3.3-megohm resistor
R4, R6—10,000-ohm resistor
R5—1-megohm resistor
S1—Normally open pushbutton switch

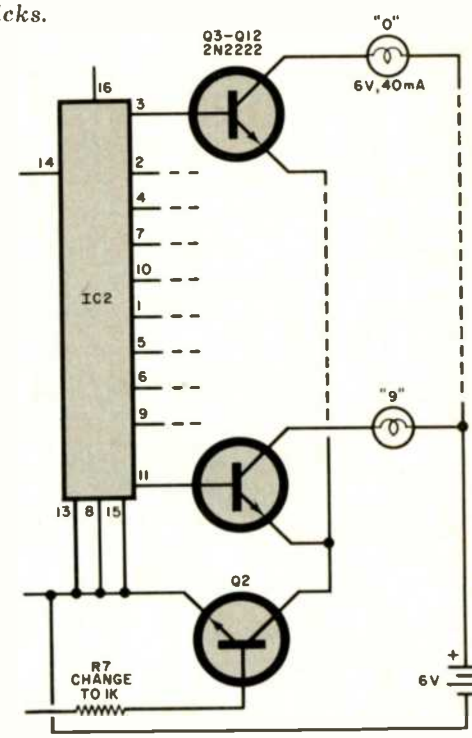


Fig. 5. Modifying the Wheel of Fortune for use with conventional 6 volt lamps.

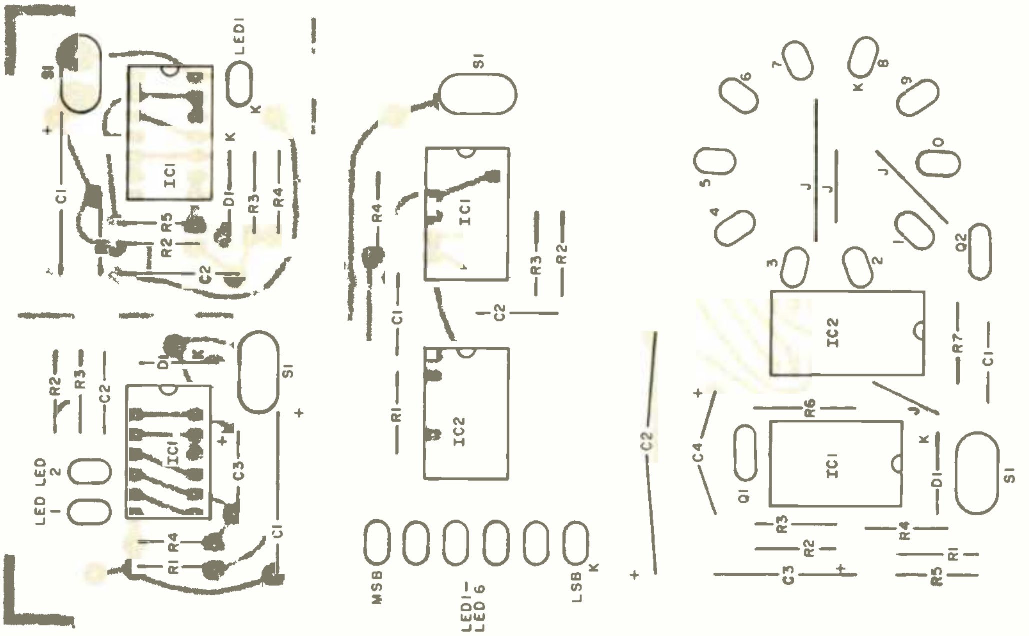
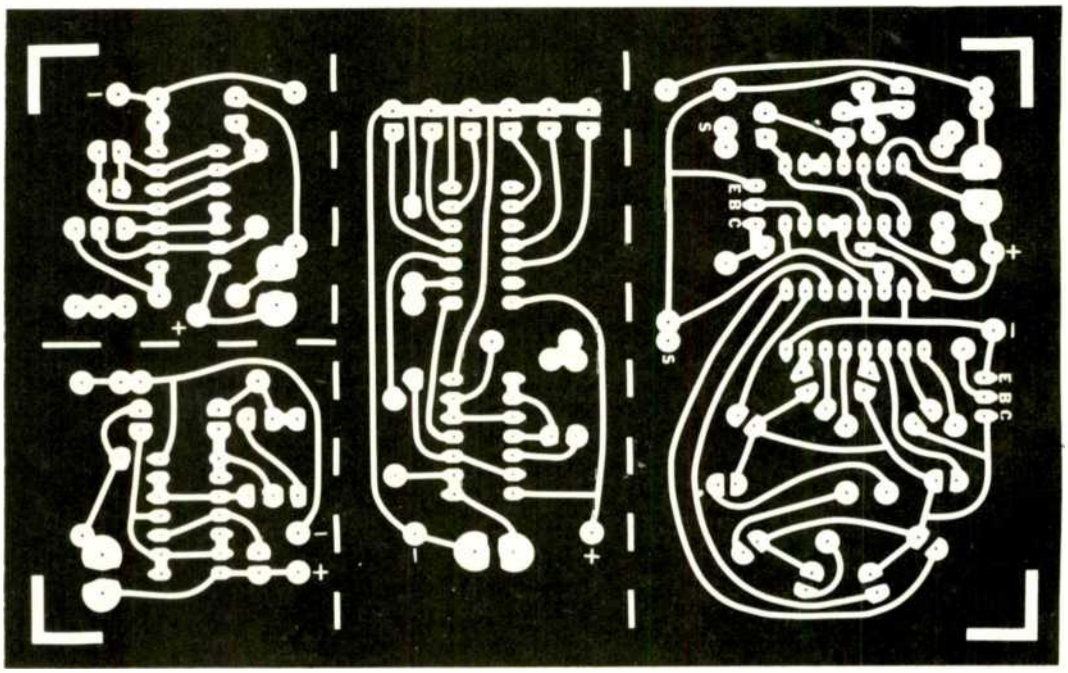


Fig. 6. Foil pattern and component installation. The four circuits are separated along the dotted lines.

Note: Pc board available from Ray Wilkins, Box 551, Hanover, NH 03755 for $5.50 ppd.

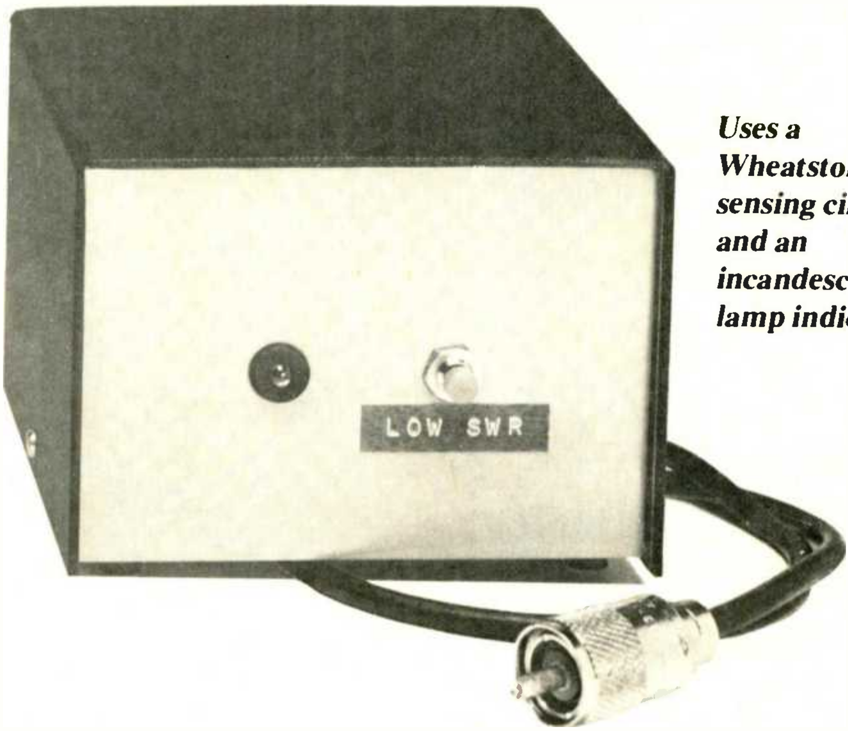


able frequency oscillator operating exactly like the oscillator in the Fig. 2 flasher circuit. Then *IC2* is a combination decade counter, decoder and driver that powers 10 LED's in sequence, with the LED's arranged in a circular display. Each pulse from the oscillator advances the count by one.

The oscillator pulses are buffered by *IC1D* and amplified by transistor *Q1* to drive a small loudspeaker. Capacitor *C3* affects the speed of rotation, while *C2* determines the total length of time that the display stays lit. The dc voltage across *C2* is also applied to a pair of buffering inverters (*IC1E* and *IC1F*) with the output used to turn on switching transistor *Q2*. When this transistor is saturated, it allows the LED's to turn on. When the voltage across *C2* drops, the output of inverter *IC1F* drops to zero, causing *Q2* to cut off, thus turning off the LED's.

It is possible to substitute conventional 6-volt, 40-mA lamps in place of the LED's by using the circuit shown in Fig. 5. To operate these optional lamps, an extra 6-volt battery is required.

Construction. Any type of construction can be used for any of the projects. If you want to use a printed circuit, you can use part or all of the foil pattern shown in Fig. 6. The four sections of the pattern can be separated at the dotted lines. Component layouts are also shown in Fig. 6. Install passive elements first, then the IC's. Be sure to observe the polarities of the electrolytic capacitors, diodes and IC's. Use a conventional 9-volt battery clip and leads for the connections. The red lead is positive, and the black lead is negative. ◇



Uses a Wheatstone bridge sensing circuit and an incandescent lamp indicator.

BY CASS LEWART

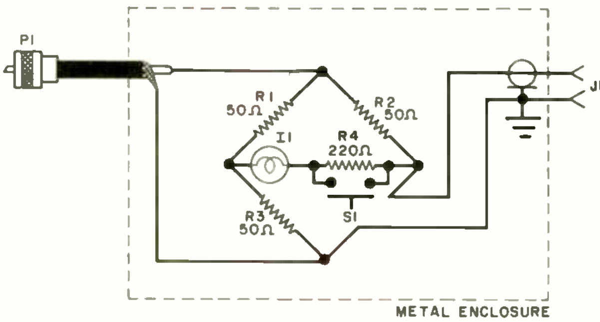
Build a Low-cost SWR TESTER

Initial adjustment of a CB antenna calls for the use of an SWR meter. However, the meter need not be left in the line after the antenna has been tuned, so most CB'ers have not felt the need to purchase one. The project presented here—an inexpensive SWR Tester—allows an operator to make periodic "good/bad" checks of his antenna system. Employing only a handful of resistors, a switch, and a small incandescent lamp, the project can be built for under $5. The SWR Tester will not yield a numerical SWR measurement, but will tell the user whether the antenna/line mismatch is severe enough to warrant further investigation.

About the Circuit. The schematic diagram of the SWR Tester is shown in the diagram. It is a Wheatstone bridge, one of whose arms is formed by the transmission line and antenna. The remaining three arms are 50-ohm carbon resistors. Indicator *I1*, a low-voltage incandescent lamp, current limiting resistor *R4* and pushbutton switch *S1* comprise the bridge's detector.

When an antenna having a 50-ohm resistive feedpoint impedance (the ideal condition for maximum power transfer) is connected to jack *J1* by a length of 50-ohm coax, the impedances of the bridge arms are equal. Therefore, the bridge is balanced and no voltage drop exists across the detector. Lamp *I1* remains dark, indicating an SWR close to unity. If the antenna's feedpoint impedance deviates from the ideal 50 ohms, the bridge becomes unbalanced and a voltage drop exists across the detector.

An antenna/feedline impedance mismatch (that is, an SWR) of about 2.5:1 will produce a voltage drop across the detector sufficient to cause *I1* to glow.

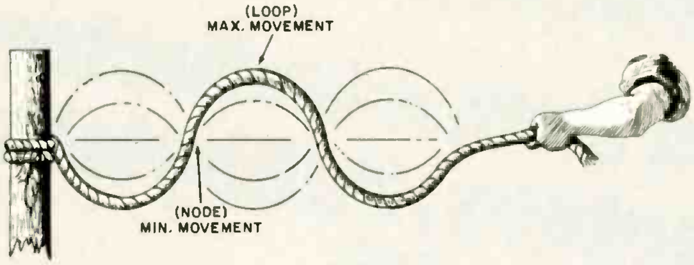


Schematic diagram of tester. The antenna/feedline combination forms the fourth leg of a Wheatstone bridge.

PARTS LIST

J1—SO-239 coaxial connector
I1—1.5-volt, 25-mA miniature incandescent lamp (Radio Shack 272-1139 or equivalent)
P1—PL-259 coaxial connector
R1,R2,R3—47- or 50-ohm, 2-watt 5% carbon composition resistor.
R4—220-ohm, ½-watt, 10% carbon composition resistor
S1—Normally open pushbutton switch
Misc.—Suitable metal utility box, ceramic standoff insulators or multi-lug terminal strip, hook-up wire, RG-58-U coaxial cable, rubber grommets, machine hardware, solder, etc.

WHAT IS SWR?



Tie a rope or string to some solid, stationary object such as a tree or post, as shown in the diagram. Grasp the free end and start waving the rope up and down. You are now generating a train of waves, much in the way that a transmitter sends waves down a transmission line.

When the wave reaches the point where the rope is anchored, there is no place for it to go so it is reflected back down the length of the rope. In this way, a pattern is formed as shown, with the loops being the points of maximum movement and the nodes the points of minimum movement of the rope. The ratio of the maximum to minimum waveform amplitude along the rope (called the Standing Wave Ratio, or SWR) in this case is 1:0, or infinity. This happens because essentially no energy is being absorbed by the wall and all is being reflected back to the driving source. This is analogous to the termination of a transmission line with an impedance that is different from that of the line. If the rope were not tied to the poles and were free to continue to move so that the transmission of the wave could continue, there would be no wave reflection. Each point on the rope would then reach the same maximum amplitude and the SWR would be 1:1, or simply 1.0.

In electrical terms, SWR can be considered as the ratio between the antenna impedance and the CB transmitter output impedance, with the larger value being the dividend and the small value, the divisor. The closer the ratio is to 1:1, the more of the transmitter r-f goes to the antenna. Besides reducing the power output to the antenna, a high SWR can also damage the transmitter output stage by submitting it to either excessive voltage or current. Therefore, keeping the SWR close to 1.0 is very important.

The table shows the relationship between SWR and the power delivered to the antenna, assuming a nominal 4-watt output from the CB transmitter.

SWR	1.0	1.2	1.5	2.0	3.0	5.0
Reflection Loss (dB)	0.00	0.04	0.18	0.51	1.25	2.55
Antenna Power (watts)	4.00	3.97	3.84	3.56	3.00	2.22

The higher the SWR becomes, the brighter *I1* will glow. Closing normally open *S1* increases the bridge detector's sensitivity so that *I1* begins to glow at an SWR of about 1.5:1. Note that this causes *R4* to be bypassed, removing the resistor's protective current limiting action from the detector circuit. If *S1* is closed when a high SWR exists on the line and *I1* is glowing, the lamp might burn out.

The bridge presents a 50-ohm impedance to the transceiver's antenna output when a 50-ohm antenna is connected to coaxial connector *J1*. However, there is a 6-dB power loss associated with inserting the SWR Tester between the rig and the antenna. The project is not designed for continuous monitoring of the SWR during communications, and should be removed from the signal path after tests have been completed. This can be accomplished by either physically disconnecting the SWR Tester or the installation of a ceramic DPDT switch inside the project's enclosure to bypass the bridge circuitry.

Construction. The circuitry of the SWR Tester is very simple, and point-to-point wiring is suitable. Solder lugs mounted on ceramic standoff insulators make ideal circuit tie points, but the standoffs might be hard to find. If you can't procure them, use a multi-lug terminal strip instead.

Mount the standoffs, switch, and coaxial jack in a small metal utility box. Drill holes for the indicator lamp and RG-58-U cable. Insert grommets into these holes, mount the indicator lamp, and pass one end of an 18-to-36-inch (45.7-to-91.4-cm) length of coax through the wall of the enclosure. Form a simple loop knot to act as a strain relief. Then remove 1¼" (3.2 cm) of the outer insulating jacket at the end of the cable inside the utility box. Comb out the braid, expose a short length of the inner conductor, and wire the circuit as per the schematic diagram. Terminate the other end of the cable with *P1*, a PL-259 coaxial connector.

Checkout and Use. Attach *P1* to the transceiver's antenna output jack. Prepare a dummy load by terminating a PL-259 with a 150-ohm, 2-watt carbon composition resistor and attach it to jack *J1*. Tune the transceiver's channel selector to channel 13, or to channel 20 if the radio has 40-channel capability. Place the mode switch in the AM position if you are using an AM/SSB rig. Then key the transceiver's push-to-talk switch.

Lamp *I1* will glow brightly. Note its brightness, and repeat the procedure on the other channels. If the rig's output remains relatively constant across the band, *I1*'s brightness will not vary from one channel to the next. Next, replace the 150-ohm resistive dummy load with a 100-ohm component. Key the transmitter. With *S1* open, *I1* will be dark. Closing *S1* will cause the lamp to glow.

The SWR Tester is now ready for use. Connect the coaxial feedline from the antenna to jack *J1*. If the antenna has been properly tuned and is in good working order, the lamp will remain dark when *S1* is open and the transceiver is keyed. The indicator might glow when *S1* is closed, especially when the channel selector is set to either end of the band and the antenna has been tuned to the center channel. This is normal because it is difficult to maintain a close impedance match over a wide band of frequencies. Short mobile whips with large loading coils are subject to such bandwidth limitations almost as a matter of course.

If the indicator glows when *S1* is open no matter which channel is selected, you should inspect the antenna and feedline for oxidized or corroded connections, clean metal-to-metal contact between the ground plane (vehicle body) and antenna base, etc. If no suspicious conditions are discovered, retune the antenna using an SWR meter and/or a field strength meter.

After you have retuned the antenna or completed your SWR tests, remove the project from the signal path—either physically or by means of a bypass switch. Otherwise, signals passing from the transceiver to the antenna (and vice versa) will be substantially attenuated. ◇

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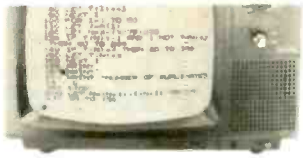

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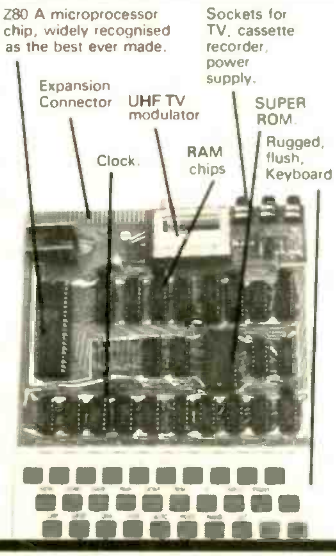

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Micro-PROCESSOR MICROCOURSE

PART 1. NUMBER SYSTEMS

A series devoted to understanding and working with these omnipresent digital devices.

THE MICROPROCESSOR has ushered in a new era of electronics. Just as the transistor conquered the vacuum tube and the integrated circuit replaced a handful of transistors, the microprocessor can replace dozens or even a hundred or more IC's.

The conventional digital logic circuit is "hardwired" and its operation cannot be easily altered after it's built. The microprocessor, however, is functionally equivalent to the central processing unit of a digital computer. Add some memory, and the microprocessor can be programmed to function as a digital controller, calculator, computer, or a dedicated logic circuit. Merely replacing the instructions in the memory with new ones will completely change the role of the microprocessor.

Most electronics enthusiasts, from professionals to hobbyists, are aware of microprocessors and some of the things they can do. Computer hobbyists are particularly close to microprocessors since inexpensive hobby computers were first made possible by the Intel 8008 and 8080 microprocessors.

However, microprocessors are so new and different that many of those who are interested in electronics have not yet become familiar with their basic operating principle, much less their programming requirements. The "Microprocessor Microcourse" is a series of articles that reviews many of the basic operating principles of digital logic circuits and culminates with a detailed description of the architecture and operation of PIP-2, a simple tutorial microprocessor.

The simplest digital logic elements operate on the basis of the presence or absence of an electrical signal. This two-state situation can be used to represent numbers and implement operations in the two-digit binary number system. We'll learn more about the devices and circuits that perform the functions later. First, let's review the basics of binary and a few other number systems.

If you learn how microprocessors work, you'll understand their role in microwave ovens, CB transceivers, autos and computers.

Number Systems. The ten-digit decimal number system is very easy to learn and use. At least that's what most of us were taught in school. But think about decimal arithmetic for a moment. To add any two decimal numbers, for example, you must first have memorized 100 individual addition rules!

What are these rules? They're numerical relationships like $1 + 1 = 2$; $4 + 5 = 9$; $3 + 7 = 10$; etc. Simple? Yes, almost transparently so, but only because we have already memorized them.

As you can see, the "simple" decimal number system isn't very simple at all. And we haven't even covered the rules required to subtract, multiply and divide decimal numbers. In all, there are literally *hundreds* of individual rules for performing the various operations of decimal arithmetic.

It took you five or six years to master the rules of decimal arithmetic, but you can master the rules of binary arithmetic in only five or six *minutes*. The binary system has only two digits or *bits*, 0 and 1, so only a few rules are necessary for performing binary arithmetic.

Here, for example, are the rules for binary addition:

$0 + 0 = 0$
$0 + 1 = 1$
$1 + 0 = 1$
$1 + 1 = 0$, carry 1 or 10
$1 + 1 + 1 = 10 + 1 = 11$

You can use these five rules to add any two binary numbers. There are equally simple rules for binary subtraction. And since multiplication and division can be accomplished by, respectively, repeated addition and subtraction, the rules for binary arithmetic are far simpler than those for decimal.

You can also use the binary addition rules to count in binary. Start with 0, add 1, and continue adding 1 to consecutive sums. This procedure is called incre-

BY FORREST M. MIMS

menting, and it allows us to quickly generate the first sixteen binary numbers:

0	100	1000	1100
1	101	1001	1101
10	110	1010	1110
11	111	1011	1111

Computer specialists frequently refer to binary numbers like these as *words* or *bit patterns* since they are often used to represent computer instructions and other nonnumerical functions. Words having eight bits are commonly used; they are called *bytes*. A word having four bits is a *nibble*.

Though binary arithmetic is easy to learn, the binary number system has a major drawback from the human perspective. Binary numbers (or words) are often long and cumbersome, difficult to remember, prone to transpositional errors, and difficult to vocalize. For example, a decimal number that uses only a digit or two will require from one to seven bits when expressed in binary. The decimal number 99 is easy to pronounce and remember. Its binary counterpart is an awkward 1100011.

Computer enthusiasts have invented several handy shortcuts and tricks for remembering binary numbers and converting them into their decimal counterparts. These methods are going to become almost second nature to the microprocessor generation, so let's have a look at them.

Converting Binary to Decimal. Converting binary numbers to their decimal equivalents is easy once you know how to expand an ordinary decimal number into its component parts. For example, 653 is 600 + 50 + 3.

The position of the digits in a number like 653 determines the power of ten by which the respective digits are multiplied. Thus,

$$\begin{aligned} 653 = 6 \times 10^2 &= 600 \\ 5 \times 10^1 &= 50 \\ 3 \times 10^0 &= 3 \\ \hline &\ 653 \end{aligned}$$

Binary numbers can be expanded using this same method—and in the process converted into their decimal counterparts. Since the binary system has only two bits, the position of a bit in a binary number determines by which power of *two* the bit is multiplied. Thus,

$$\begin{aligned} 1001 = 1 \times 2^3 &= 1000 \\ 0 \times 2^2 &= 0000 \\ 0 \times 2^1 &= 0000 \\ 1 \times 2^0 &= 0001 \\ \hline &\ 1001 \end{aligned}$$

We can carry this expansion one step further and convert 1001 into its decimal equivalent. Just convert the powers of two into their decimal values and add the products:

$$\begin{aligned} 1001 = 1 \times 8 &= 8 \\ 0 \times 4 &= 0 \\ 0 \times 2 &= 0 \\ 1 \times 1 &= 1 \\ \hline &\ 9 \end{aligned}$$

An even faster way to convert a binary number to its decimal form is to list the ascending powers of two over each bit in the number beginning with the least significant bit. Then add the powers of two over the 1 bits and ignore those over the 0 bits. Thus, to convert 1100110 to decimal:

```
 64 32 16 8 4 2 1
  1  1  0 0 1 1 0
64 + 32 + 4 + 2 = 102
```

Converting Decimal Numbers to Binary. A quick way to convert decimal numbers into their binary counterparts is to repeatedly divide the decimal number by two. The remainders of each division, which will always be 0 or 1, become the binary number. Let's convert 102 into binary using this method:

```
102/2 = 51, remainder 0
 51/2 = 25,     "     1
 25/2 = 12,     "     1
 12/2 = 6,      "     0
  6/2 = 3,      "     0
  3/2 = 1,      "     1
     Final      "     1
        102 =   1 1 0 0 1 1 0
```

Octal and Hexadecimal Numbers. Often binary numbers are used to represent computer instructions and operations. For example, 01110110 is the binary equivalent of the decimal number 118. 01110110 is also the instruction code selected by Intel to represent the instruction HLT (halt) for its 8080 microprocessor.

Binary numbers are also used to represent memory addresses inside a computer. Thus 01110110 can represent the decimal number 118, the instruction HLT, or the 119th address in a computer memory (the first address being 00000000).

Since binary numbers play such an important role in microprocessors and computers, you'll want to learn about a couple of very handy time and space saving shortcuts called the *octal* and *hexadecimal* number systems.

Decimal numbers have ten as their base; therefore the largest decimal digit is 9. Octal numbers have eight as their base, and that means the largest octal digit is 7. Since the binary equivalent of the decimal digit 7 (which is equivalent to the octal digit 7) is 111, it's easy to convert any binary number into its octal counterpart by simply dividing the bits in the number into groups of three and converting each group into its decimal equivalent. Thus, the binary number 01110110 becomes 01 110 110 or 166 in octal.

When listing numbers having different bases, it's customary to indicate each number's base with a subscript. Therefore 166_8 is an octal number. Obviously 166_8 is much easier to remember than 01110110_2. And it's easy to convert 166_8 back to binary by simply writing out the binary equivalent for each digit:

```
1 = 01
6 =      110
6 =           110
    01   110  110
```

Hexadecimal numbers have sixteen as their base. They're commonly used to simplify 8-bit bytes into easily remembered two-character numbers.

The hexadecimal digits are 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F. Don't let the letters A-F confuse you. There are more than enough decimal digits for the binary and octal systems, but not enough for all sixteen hexadecimal digits. The letters A-F complete the six digit spaces beyond the ten digits 0-9.

It's easy to convert a binary byte into hexadecimal or simply *hex*. First, divide the byte into two nibbles. Then assign the hex equivalent to each nibble. 1111_2 is F_{16} and 0110_2 is 6_{16}. Therefore, 11110110_2 is $F6_{16}$.

To convert a hex number to binary, just assign the binary equivalent to each hex digit. Thus $F6_{16}$ is 1111_2 and 0110_2 or 11110110_2.

Incidentally, though it's correct to identify a hex number with a subscript 16, it's not necessary to tag on the subscript if the number includes one of the six digits borrowed from the alphabet. Everyone seeing it will know it's hex. Also, some computer companies identify hex numbers with the $ sign. So F6E9 is the same as $F6E9.

Most of today's microprocessors use 8-bit address and instruction words, so you'll often see programs given in octal or hexadecimal. While it takes time to become used to these new number systems, especially hex, you'll find them very handy as you become more involved with microprocessors. The conversion table given below will help you

Decimal	Binary	Octal	Hexa-decimal
0	0	0	0
1	1	1	1
2	10	2	2
3	11	3	3
4	100	4	4
5	101	5	5
6	110	6	6
7	111	7	7
8	1000	10	8
9	1001	11	9
10	1010	12	A
11	1011	13	B
12	1100	14	C
13	1101	15	D
14	1110	16	E
15	1111	17	F

become more familiar with both octal and hexadecimal numbers. ◇

PART 2. BASIC DIGITAL LOGIC

Micro-PROCESSOR MICROCOURSE

The Basic Logic Gates. All digital logic circuits, from the simplest counter to the most sophisticated microprocessor, are made from interconnected combinations of simple building-block circuits called logic gates. There are four basic gates, and they are designated according to their function as YES, NOT, AND, and OR circuits. Each of these basic gates has one or more inputs, a single output, and a couple of power supply terminals.

Various combinations of the binary bits 0 and 1 can be applied to the inputs of a gate by allowing a low voltage to represent logic 0 and a high voltage logic 1. This is called positive logic. In negative logic, the definitions are reversed.

The YES gate transmits the logic state (0 or 1) at its single input directly to its output. It's often used to interface logic circuits that are otherwise electronically incompatible. For this reason it's often called a *buffer*.

The NOT gate inverts or complements the logic state at its single input so it's often called an inverter. The NOT function is often indicated by a bar or vinculum over the symbol for an input or output that's been inverted. Thus if A is 0 and B is 1, then $A = \overline{B}$. (The $\overline{B}$ is read and sometimes written "not B.")

The AND gate is a decision making circuit with two or more inputs. The output of the AND gate is logic 0 unless *all* the inputs (inputs A *and* B *and* C . . .) are logic 1.

The OR gate is also a decision making circuit with two or more inputs. Its output is logic 0 unless *any* or *all* of its inputs (input A *or* B *or* C . . .) are 1.

The operation of a gate can be defined by a table that shows the combination of input bits that produces a particular output bit. Such a table is called a truth table. The truth tables and standard symbols for each of the four basic logic gates are shown in Fig. 1.

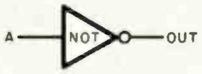
Compound Logic Circuits. Combining two or more of the basic gates into a compound logic circuit can provide some very important operating features. The two most important compound logic circuits are the AND-NOT and OR-NOT combinations. These are called the NAND and NOR gates and their symbols and truth tables are shown in Fig. 2.

As shown in Fig. 3, various combinations of NAND (or NOR) gates *alone* can simulate YES, NOT, and AND circuits. This is important, but the most fascinating characteristic of the NAND and NOR functions is their logic equivalence. Thanks to a rule known as DeMorgan's theorem, a positive logic NAND gate is equivalent to a negative logic NOR gate and vice versa.

You can prove this for yourself by writing the appropriate truth tables and finding that they are indeed identical. DeMorgan's theorem simplifies digital logic to the point where combinations of only NAND gates or NOR gates can implement any logic function. Figure 4, for example, shows how NAND gates alone can implement both the OR and NOR functions. Notice how NAND gates are used as inverters to change the inputs from positive to negative logic.

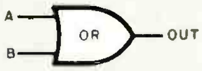
(Continued on page 118)

A	OUT
0	0
1	1



A	OUT
0	1
1	0

A	B	OUT
0	0	0
0	1	0
1	0	0
1	1	1



A	B	OUT
0	0	0
0	1	1
1	0	1
1	1	1

Fig. 1. The four basic logic gates: YES, NOT, AND, OR.

A	B	OUT
0	0	1
0	1	1
1	0	1
1	1	0

A	B	OUT
0	0	1
0	1	0
1	0	0
1	1	0

Fig. 2. A NAND gate and a NOR gate, with their repective truth tables below.

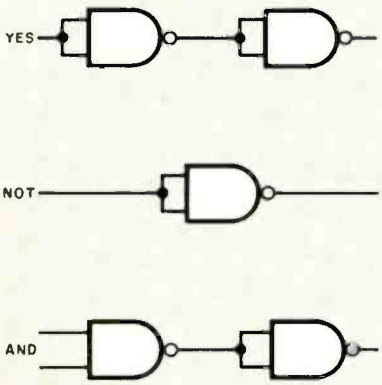


Fig. 3. Using NAND gates to simulate other gates. At top, YES; middle, NOT; bottom, AND.

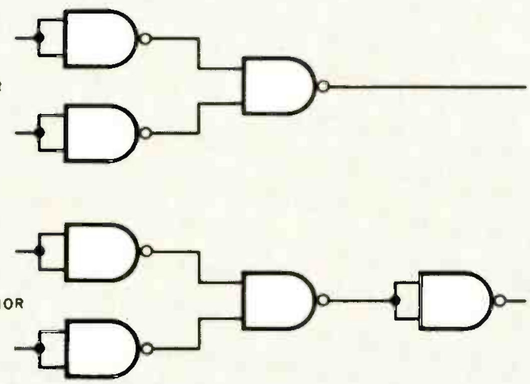


Fig. 4. Using NAND gates to prove DeMorgan's theorem. At top, OR; on the bottom, NOR.

Complex Logic Systems. Simple and compound gates can be tied together to implement a countless variety of logic functions. Some of the resulting logic systems contain only a handful of gates; others may use dozens or even hundreds of gates. All of these complex logic systems can be divided into two broad categories: combinational and sequential.

Combinational circuits are characterized by their fast acting operation. Exclusive of the brief time delay required for its gates to react to an incoming logic 0 or 1 (the propagation time), the output(s) of the most complex combinational circuit instantaneously reflects the pattern of 0's and 1's at its input(s).

Sequential circuits include storage or delay elements that permit the logic result of a previous input to directly influence a new input. This makes sequential circuits slower than combinational circuits. On the other hand, it makes possible important applications such as memory registers, counters, dividers, sequencers, and microprocessors.

Combinational Logic Circuits. The simplest combinational logic circuit is the Exclusive-OR gate. The symbol and truth table for this circuit are shown in Fig. 5.

Look at the Exclusive-OR truth table for a moment. The Exclusive-OR function is just that; it gives a logic 1 output *only* if one *or* the other of its two inputs is logic 1. Otherwise the output is 0. This is identical to the binary addition rules with the exception of the carry output needed for 1 + 1.

It's easy to generate the carry output bit needed to use the Exclusive-OR circuit as a binary adder. Look at the logic circuit for an Exclusive-OR in Fig. 6. If you'll study the operation of this circuit, you'll find that the output of AND gate 1 provides the carry output we need. In the other circuit in Fig. 6, we use this carry output to form a circuit that can add any two binary bits. It's known as a *half adder*.

A half adder is useful, but it can only accept two input bits. To complete the binary addition rules, we need an adder circuit that will accept a carry bit as well. The circuit that accomplishes this goal is the *full adder*. As you can see in Fig. 7, a full adder can be made from two half adders and an OR gate.

It's possible to connect a string of adders together to form a binary adder capable of adding multiple-bit binary words. Figure 8, for instance, shows a 4-bit adder that will sum two words applied to its inputs. Try adding 1101 + 0101 using this adder to prove to yourself it really adds.

A binary adder forms part of a microprocessor's arithmetic-logic unit (ALU), a combinational circuit that performs addition, subtraction, and various logic operations upon two incoming words. The ALU is instructed what operations it is to perform by binary signals applied to its control inputs. We'll learn more about the ALU later in this course.

Encoders and Decoders. An encoder is a combinational network of OR gates that converts or encodes a nonbinary input into binary. For example, an octal-to-binary encoder has eight inputs (one for each octal digit) and three outputs (one for each binary bit). A logic 1 at one of the inputs produces the binary equivalent at the output.

Encoders can provide other conversion operations, too. Keyboard encoders, for instance, convert individual key positions into their assigned binary words. An example is the ASCII (*A*merican *S*tandard *C*ode for *I*nformation *I*nterchange) encoded keyboard, which generates the 7-bit word 0100101 when the % key is pressed.

A decoder is a combinational circuit that converts a binary number at its inputs into a logic 1 at one or more of its outputs. In digital electronics it's often necessary to convert a binary number into some other format, and one common decoder application is the conversion of binary numbers into the format required to activate the appropriate segments in a 7-segment decimal display.

Decoders are also used to decode binary instructions in a microprocessor, assist in the production of sequential timing signals for advanced logic circuits, and convert binary numbers into their octal, decimal, and hexadecimal counterparts. Figure 9 summarizes the operation of encoders and decoders.

Multiplexers and Demultiplexers. The multiplexer is the digital logic equivalent of a multiple-position rotary switch. A typical multiplexer is a combinational logic circuit that selects one of several input lines and applies any data on that line to a single output. A special set of address inputs determines which input line is selected.

One typical multiplexer has eight data inputs, three address inputs, and a single data output. When the address 101

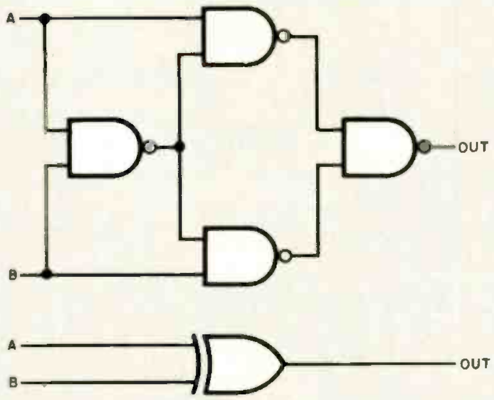


Fig. 5. The combinational circuit at top provides an Exclusive-OR, as shown in the middle. The truth table is below.

A	B	OUT
0	0	0
0	1	1
1	0	1
1	1	0

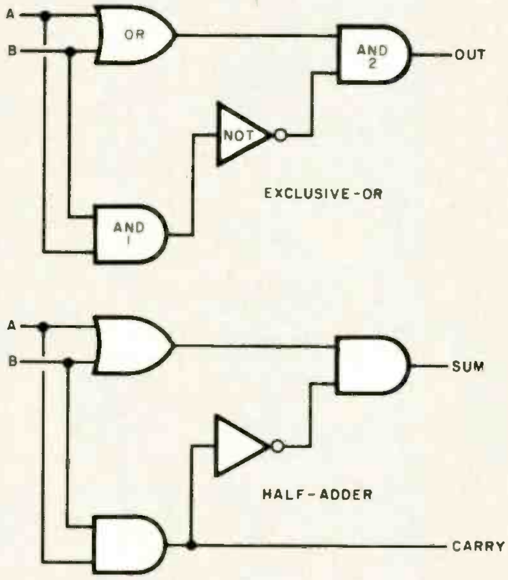


Fig. 6. How an Exclusive-OR can be used to make a half-adder combinational circuit.

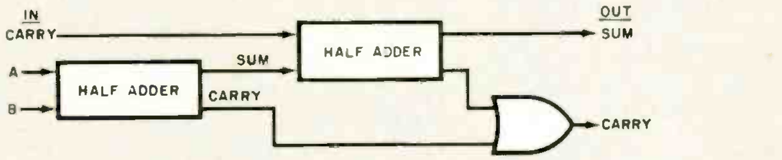
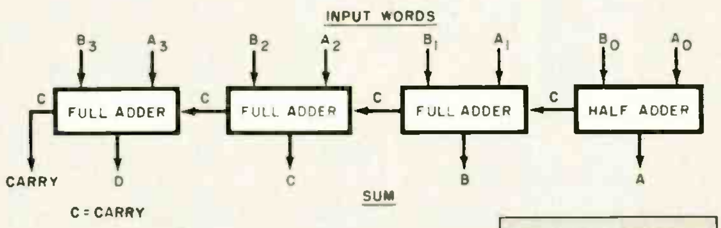


Fig. 7. Two half adders and an OR gate can be used to make a full adder circuit.



EXAMPLE: 1101 = WORD A
+0101 = WORD B
10010 = SUM

Fig. 8. A string of full adders connected together can be used to form a binary adder, capable of adding binary words.

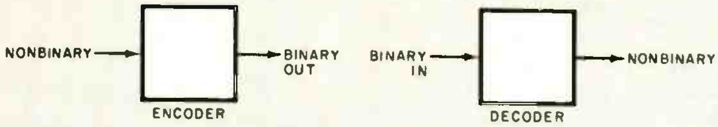


Fig. 9. An encoder is a combinational network that converts a nonbinary input to a binary output. A decoder does just the reverse.

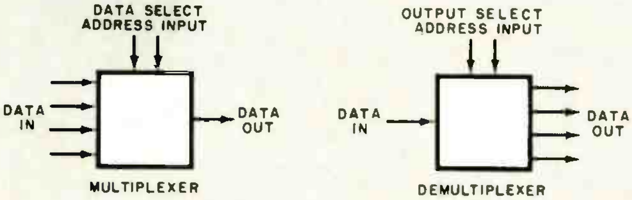
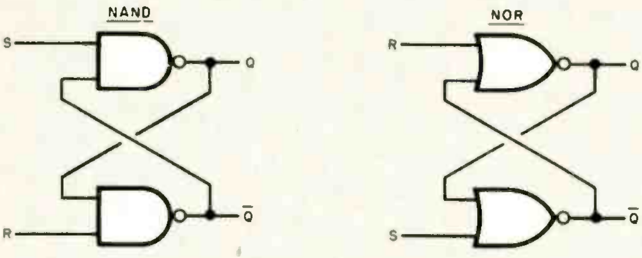


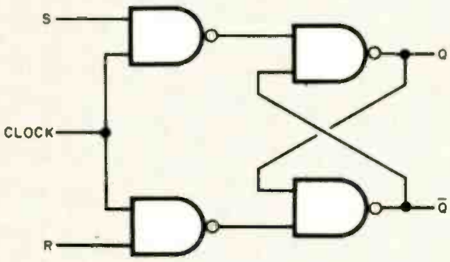
Fig. 10. A multiplexer is the equivalent of a multiple-position switch. A demultiplexer converts multiplexed data back to original form.



S	R	Q	$\overline{Q}$
0	0	NOT ALLOWED	
0	1	1	0
1	0	0	1
1	1	NO CHANGE	

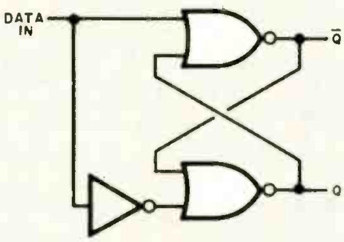
S	R	Q	$\overline{Q}$
0	0	NO CHANGE	
0	1	0	1
1	0	1	0
1	1	NOT ALLOWED	

Fig. 11. Simplest flip-flop is made from two NAND's or two NOR's with truth tables as shown.



CLOCK	S	R	Q	$\overline{Q}$
0	0	1	NO CHANGE	
0	1	0	NO CHANGE	
1	0	1	1	0
1	1	0	0	1

Fig. 12. A clocked RS flip-flop is a sequential circuit with truth table as shown here.



D	Q	$\overline{Q}$
0	0	1
1	1	0

Fig. 13. A data, or D, flip-flop is made by adding an inverter to input of one flip-flop.

is applied to the multiplexer, input 5 is connected to the output.

A common application for multiplexers is driving the readouts of pocket calculators to reduce the number of pin connections on the calculator's chip. The multiplexer lets all the digits in the readout share a common set of terminals. It activates each digit or one segment in all the digits in rapid succession to fool the eye into thinking the display is continually illuminated.

The demultiplexer transfers the binary data at its input onto one of two or more output lines. Like the multiplexer, an address input controls the output.

Demultiplexers are used with multiplexers to convert multiplexed data back to its original form. They can even function as decoders by applying a logic 1 to the single input and using the address inputs as data inputs. Figure 10 summarizes the operation of multiplexers and demultiplexers.

Sequential Logic Circuits. Unlike combinational logic circuits, sequential circuits have memory. Their output(s) can reflect the effect of an input that occurred seconds or even days earlier.

The simplest sequential circuit is the flip-flop. A microprocessor together with a read/write memory incorporates dozens—perhaps thousands—of flip-flops.

There are several different kinds of flip-flops, but all are capable of storing a single binary bit. This makes possible such applications as counters, dividers, memory registers, and others. Here are the four basic kinds of flip-flops.

The RS Flip-Flop. The simplest flip-flop is made from two NAND or NOR gates with crisscrossed inputs and outputs as shown in Figure 11. This basic circuit is called a reset-set (RS) flip-flop or simply a *latch*. Figure 11 also shows the truth tables for NAND and NOR gate versions of the RS flip-flop.

Notice that the two outputs of the RS flip-flop complement one another. When Q is logic 1, the flip-flop is *set*. When Q is logic 0, the flip-flop is *reset* or *cleared*.

Clocked RS Flip-Flop. The basic RS flip-flop is *asynchronous*; it responds to inputs as soon as they occur. A way to synchronize the operation of the RS flip-flop with other logic circuits is to gate its inputs so they can respond only when activated by a logic 1 from a *clock*. A clock is a sequential circuit that produces a stream of alternating 0's and 1's. Fig. 12 is a clocked RS flip-flop.

The Data or D Flip-Flop. The D flip-flop is a further modification of the clocked RS flip-flop. As shown in Figure 13, an inverter is added to one of the two inputs of the flip-flop and the remaining input and the inverter's input are tied together. This guarantees that the inputs to the RS section of the flip-flop will always complement one another. And it insures that the logic state of the Q output will always correspond to the logic state of the D input.

The JK Flip-Flop. The JK flip-flop is a clocked RS flip-flop with a refinement that allows a logic 1 to be simultaneously applied to both inputs. Figure 14 shows the logic circuit and truth table for this flip-flop. The JK flip-flop can easily simulate any of the other kinds of flip-flops, so it's commonly used in sequential logic circuits.

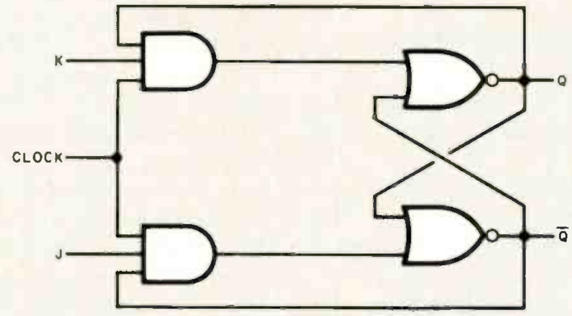
The JK flip-flop can be used to make a toggle or T flip-flop. The J and K inputs are tied together and called the T input. When a logic 1 is applied to T, the flip-flop changes state or toggles each time a clock pulse arrives.

Storage Registers. A string of D flip-flops called a *register* can be used to store a binary word. A register like this can be made far more useful by adding some combinational logic to simultaneously clear all the flip-flops to 0 when a logic 1 is applied to a *clear* input. A *load* input can also be added to force the register to ignore incoming data. When the load input is logic 1, the input data will be accepted by the register when the next clock pulse arrives.

Data storage registers like this are sometimes called *buffer* registers. They're used in logic circuits and in microprocessor units to temporarily hold a data word.

Shift Registers. Considerably more versatile than the buffer register is the shift register shown in Fig. 15. This particular register accepts data a bit at a time (serial input) while making available the contents of all its flip-flops simultaneously (parallel output). The data bits in the register are shifted right a bit at a time by clock pulses to make room for incoming bits.

Universal shift registers that can accept and output data as serial bits or parallel words as well as shift the data left or right are available. The various operations of a universal shift register are selected by applying logical 0's and 1's to an array of control inputs. Microprocessors incorporate at least one shift register to perform some of the data manipulation required to multiply and divide



Q = 0

J	K	Q*
0	0	0
0	1	0
1	0	1
1	1	1

*(after clock pulse)

Q = 1

J	K	Q*
0	0	1
0	1	0
1	0	1
1	1	0

*(after clock pulse)

Fig. 14. The JK flip-flop is a clocked RS flip-flop that allows a logic 1 to be simultaneously applied to both inputs. Shown here is a NOR gate version with truth tables for Q = 0 and Q = 1.

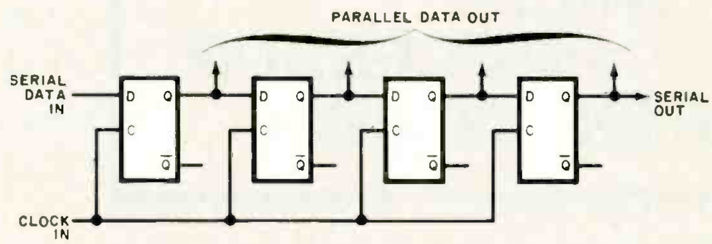


Fig. 15. This shift register made from D flip-flops accepts data a bit at a time and has a serial output as well as parallel outputs from each flip-flop.

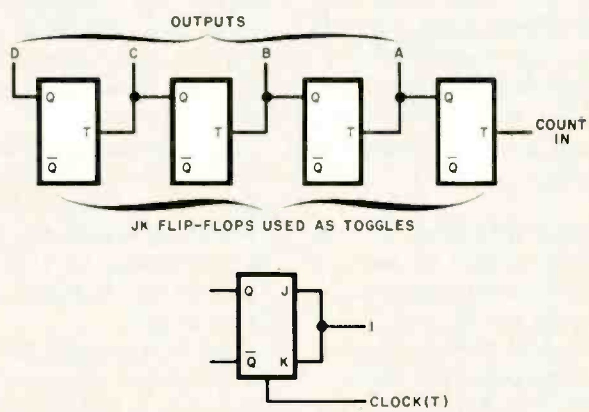


Fig. 16. A four-bit counter made from T flip-flops that will count from 0000 to 1111 and then recycle.

binary numbers.

Counters. Remember the toggle or T flip-flop we discussed earlier? The Q output of this flip-flop alternates between logic 0 and 1 for each incoming clock pulse: 0 . . . 1 . . . 0. . . 1 . . . In other words, the Q output is logic 1 for *half* the incoming clock pulses. This means a single flip-flop can be used to divide an incoming stream of bits by two. The Q output of a toggle flip-flop also counts! Thus, 0 . . . 1 . . . 0 . . . 1 . . . is the same as counting from 0 to 1 in binary over and over again.

Higher capacity binary counters (and dividers) can be made from a string of T flip-flops. Just connect the Q output of one flip-flop to the clock input of the next flip-flop. Figure 16, for instance, shows a 4-bit counter made from four T flip-flops. This counter will count from 0000 to 1111 and then recycle.

There are many different kinds of flip-flop counters. The *modulo* of a counter specifies the maximum count it reaches before recycling. Modulo 10 counters are very popular because they recycle after the tenth input pulse and therefore provide a convenient way to count in decimal. They are often called BCD (*bi*nary *c*oded *d*ecimal) counters. Their count sequence is 0000 (0_{10}) . . . 0001 (1_{10}) . . . 0010 (2_{10}) . . . . . . 1001 (9_{10}) . . . 0000 (0_{10}) . . . .

Counters can have a variety of control inputs. A typical counter, for example, can count up *or* down. It may also have control inputs for clearing the count to all 0's, presetting the count to any desired value, and enabling the counter to count. Finally, since counters store the accumulated count until the next clock pulse arrives, they can be considered storage registers. ◇

PART 3.
MEMORIES, BUS ORIENTED LOGIC, AND MICROPROCESSOR ORGANIZATION.

Micro-PROCESSOR MICROCOURSE

IN PRECEDING parts of this course, we learned about binary, octal, and hexadecimal number systems. We also covered basic logic gates and combinational and sequential logic circuits.

This installment will describe semiconductor memories and show how three-state logic allows a logic circuit to transfer data to one or more other circuits over a common array of conductors called a *bus*. It will conclude with a look at the basics of microprocessor (or MPU) organization.

Memories. A microprocessor alone is merely a collection of logic circuits on a silicon chip, and must be provided with a detailed list of instructions called a *program* before it can perform useful work. The program, along with input data and even output data from the microprocessor, is stored in a memory.

Memories store information as individual bits (0's and 1's) or bit patterns (words). As we learned in Part 1, a binary word can indicate a numerical value (data), a memory address, or a computer instruction. This makes a memory device an exceptionally versatile component and an indispensable partner to the microprocessor.

Microprocessors can be used in conjunction with any kinds of memories ranging from magnetic bubbles and cores to cassette tapes and floppy disks. The two most important microprocessor memories, however, are semiconductor ROM's and RAM's.

ROM's are *r*ead-*o*nly *m*emories, since they contain information that can only be read out, and not modified or erased. RAM's are *r*ead/*w*rite *m*emories, and they generally store temporary data. The data they store can be easily modified or erased.

Both ROM's and RAM's are available as integrated circuits with dozens to thousands of individual binary storage cells printed, etched, diffused, and interconnected with an aluminum metalization pattern on a silicon chip. Thanks to the ingenious use of on-chip combinational logic decoders, it's possible to access all the storage cells in even a very large memory with relatively few input lines. A simplified view of how an *address decoder* accomplishes this is shown in Fig. 1. As you can see, simply applying the appropriate address to the memory's address lines causes the designated bit or word to appear on the output lines.

ROM's and RAM's store data as individual bits or multiple bit words (usually 4-bit nibbles or 8-bit bytes). Either way, the address decoder insures a fixed and very rapid time to access *any* bit or word in the memory. This feature is called *random access*. *Serial access* memories, like magnetic tape and high-capacity shift registers, are slower since their contents must be searched bit-by-bit to find a specified address.

ROM. The typical ROM is an array of intersecting conductors as shown in Fig. 2. A diode connecting two intersecting conductors represents a logic 1. The absence of a diode at an intersection is a logic 0. Information is stored in a ROM when it is manufactured and is therefore permanent. The information can be read out, but new information can never be written into the ROM.

ROM's can store binary data, addresses, or instructions. They can even simulate a logic circuit. Figure 3, for example, shows a diode ROM programmed with the truth table of the Exclusive-OR circuit. This circuit normally requires at least four logic gates, each containing several transistors. As you can see, the ROM version is considerably simpler.

It's easy to program a ROM to simulate virtually any combinational logic circuit, and to illustrate this, Fig. 4 shows a ROM programmed as an octal-to-binary encoder, a circuit usually designed with a network of OR gates. Designing this encoder using logic gates is both tedious and time consuming, but anyone can design a ROM encoder. All that's needed is the appropriate truth table, such as that shown below:

Octal Input								Binary Output		
0	1	2	3	4	5	6	7	2^2	2^1	2^0
1	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1
0	0	1	0	0	0	0	0	0	1	0
0	0	0	1	0	0	0	0	0	1	1
0	0	0	0	1	0	0	0	1	0	0
0	0	0	0	0	1	0	0	1	0	1
0	0	0	0	0	0	1	0	1	1	0
0	0	0	0	0	0	0	1	1	1	1

Looking at Fig. 4, notice how the placement of the diodes in the ROM corresponds to the 1's in the output half of the truth table? The ROM is now programmed as an octal-to-binary encoder.

Using a ROM is as easy as programming it. Just activate the appropriate input line and the designated bit pattern appears on its output lines.

ROM's are available as reasonably priced standard parts programmed for such roles as encoders, decoders, and look-up tables of trigonometric and other mathematical functions. Semiconductor companies will also make custom ROM's upon request, a rather costly procedure unless thousands of identical ROM's are ordered. But how about a few one-of-a-kind custom ROM's for prototype or hobbyist applications?

The best solution here is the *programmable* ROM or PROM. A PROM is a ROM with diodes at *all* its storage locations. A truth table is loaded into the PROM by applying brief, high-current pulses to the inputs connected to the diodes that are *not* wanted. This vaporizes a thin layer of metalization called a *fusible link* that connects the diode to the PROM's conductors.

PROM's, like ROM's, cannot be erased once they are programmed (though additional fusible links can be blown). A special *erasable* PROM, however, is available. It's programmed electrically and erased with ultra-violet radiation beamed through a quartz window that covers the silicon chip.

Various kinds of ROM's and PROM's can store from hundreds to thousands of bits. Since ROM's with storage capacities of from 2^8 (256) to 2^{16} (65,536) bits are the most common, ROM's (and RAM's) are often designated with a "k" factor that gives an approximation of their storage capacity—k comes from *kilo* and means 1,000. Thus a 1k memory stores 1,024 (2^{10}) bits, and a 4k memory stores 4,096 (2^{12}) bits.

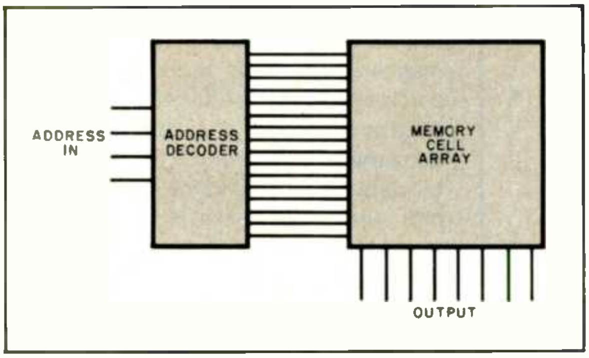


Fig. 1. How an address decoder simplifies access to a word stored in a ROM or R/WM.

Some memories store data as single bits. Therefore, a 1 × 256-bit ROM stores 256 bits of data, and an 8 × 256-bit ROM stores 256 8-bit bytes.

RAM. A RAM, like a ROM, consists of an intersecting grid of conductors on a silicon chip. However flip-flops, not diodes, are placed at the intersections in the grid. Since flip flops can be made to change states, this means the data stored in a RAM can be electrically altered or erased. It also means RAM's are more complicated and therefore more expensive than ROM's.

ROM's are classified as nonvolatile memories since they store information without the presence of electrical power. RAM's are volatile. Remove the operating power from a RAM (even momentarily) and its stored information is lost since the internal flip-flop can assume either state at random.

RAM's are sometimes used to store the kind of information stored in ROM's. More frequently, however, they're used for microprocessor data and program storage, temporary data storage, and for any application that requires a quickly alterable truth table.

A simple 4-bit register can be thought of as a RAM that can store a single 4-bit word (a 1 × 4-bit RAM). But practical RAM's have substantially more data storage capacity. Today, RAM's capable of storing 16k (16,384) bits and up to 64k (65,536) bits are available. Large-capacity RAM's like these can be operated in parallel to provide storage for multiple bit words.

Other Memories. Semiconductor RAM's AND ROM's are by far the most important microprocessor memories in use today. Other kinds of memories are also available, and since memories play such a vital role in the operation of a microprocessor you should at least be aware of them.

An important new semiconductor memory is the charge-coupled device (CCD). This device stores data as an electrical charge that can be moved from one memory cell to the next like a pail of water moving down a bucket brigade. The presence of a charge is logic 1 while no charge is logic 0. Since they must be accessed serially, CCD's are slower than ROM's and RAM's. However, CCD's can store more data on a silicon chip than a similar size ROM or

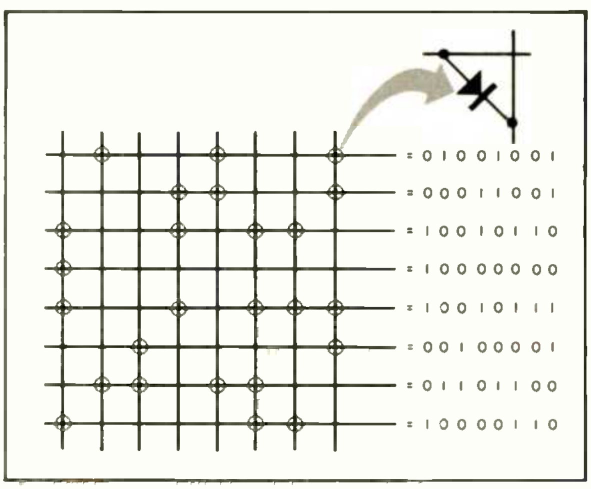


Fig. 2. A ROM is an array of intersecting conductors. When a diode connects the conductors, a logic 1 is represented.

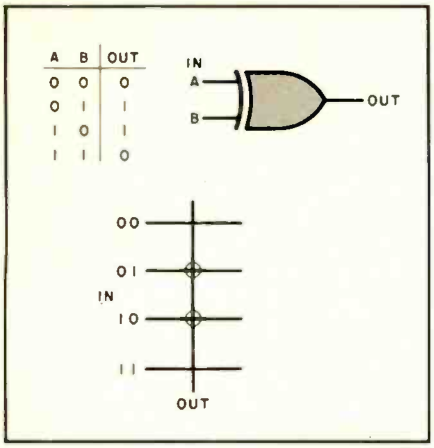


Fig. 3. At upper right is the logic symbol for Exclusive-OR, with its truth table at left. Below is the diode ROM for the same function.

RAM because the elaborate address decoders needed for random access aren't used. CCD's are read/write devices.

Magnetic bubble memories provide high-capacity read/write, nonvolatile data storage. Bits are stored as the presence (1) or absence (0) of microscopic magnetic cylinders called *domains* in a thin film of magnetic garnet or orthoferrite. The cylinders, which resemble bubbles when viewed on end through a microscope, can be rapidly moved along a path defined by a pattern of metallized bars, chevrons, or other shapes. The metal shapes are magnetized in different directions by a rotating magnetic field, and this causes the bubbles to move from one bar to the next.

Magnetic tape and floppy disk memories are commonly used with sophisticated microprocessor systems such as computers. There are several ways to store bits of data on magnetic tape, one of which is to encode logic 0 and 1 as two different audio frequency tones. Cassette recorders are inexpensive, readily available, and ideal for loading programs into the RAM of a microprocessor-based computer.

The floppy disk is a record-like disk of flexible plastic coated with the same magnetic substance used to make recording tape. Bits are stored as the presence or absence of magnetized spots on as many as a hundred or more concentric data tracks around the surface of the disk. The disk is spun at high speed, and a read/write head on a movable track permits access to any data track. Floppy disks provide very high capacity storage with considerably faster access times than magnetic tape. But floppy disk systems are expensive; they often cost more than the computer.

Three-State Logic. Thus far we've learned something about basic logic gates, combinational and sequential logic circuits, and memories. We're almost ready to begin using these various devices as electronic building blocks to design a microprocessor. All that remains is to introduce a new kind of logic circuit called the *three-state gate*.

As you will recall from Part 1, the output of *all* the logic gates and circuits we've covered so far is various combinations of 0's and 1's. This is known as two-state logic.

A third output called the high-impedance (high-Z) state is available in three-state logic. In the high-Z state the output of a three-state gate is electronically disconnected from the gate. It's as if an on-off switch between the gate and its output line were turned off. In conventional operation, when the switch is on, 0's and 1's appear at the output.

A simple three-state buffer is shown in Fig. 5. When the *control* (or enable) input is logic 1, the buffer transmits the logic state (0 or 1) at its input to its output. When the control input is logic 0, the output enters the high-Z state.

All the basic gates are available in three-state versions. And many kinds of more advanced circuits such as flip-flops, counters, registers, and combinational networks are available with three-state outputs.

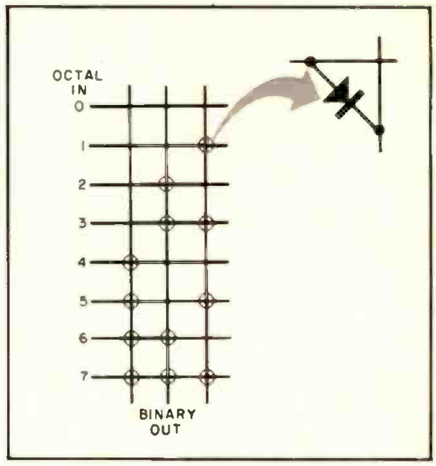


Fig. 4. A ROM programmed as an octal-to-binary encoder, a circuit usually designed with OR gates.

Three-state logic makes it possible to connect the output of two or more logic circuits to a common conductor called a *bus*. It's not possible to connect the outputs of two or more two-state gates to the same bus since some outputs may be logic 0 and others logic 1. Three-state logic means many gates can be connected to the same bus so long as the output of all but one of the circuits is in the high-Z state.

Several three-state buffers are connected to a common bus as shown in Fig. 6. Look at this circuit for a moment. Notice how the array of control inputs (C) allows data to be guided from any of the three inputs to either or both of the outputs. This operation is similar to that of a multiplexer, and three-state logic is sometimes used to simulate a multiplexer. More importantly, the circuit allows data to travel along the bus in either direction. That's why a three-state bus is often called *bidirectional*.

Register-to-Register Data Transfers. A typical microprocessor contains several data storage registers. Three-state logic provides an efficient way to transfer data from one of these registers to another.

Figure 7 shows three 4-bit registers connected to a common 4-conductor bus. The output of each register is connected to the bus through a 4-bit three-state buffer. This is why both the input *and* output lines from a register can be connected to the same bus.

Each register in Fig. 7 has three control inputs: Read, Write, and Clock. A logic 0 at its Read input places a register's output in the high-Z state and isolates the data stored in it from the bus—

Operation	Control Inputs					
	A/R	A/W	B/R	B/W	C/R	C/W
A → B	1	0	0	1	0	0
A → C	1	0	0	0	0	1
B → A	0	1	1	0	0	0
B → C	0	0	1	0	0	1
C → A	0	1	0	0	1	0
C → B	0	0	0	1	1	0
A → B & C	1	0	0	1	0	1
B → A & C	0	1	1	0	0	1
C → A & B	0	1	0	1	1	0

and therefore the other registers. A logic 1 at the Read input enables the three-state buffer and places the data in the register on the bus. Note that only *one* register can be in the Read mode at any one time; otherwise two or more registers will conflict with one another.

Data on the bus can be written into one or more registers by applying a logic 1 to the appropriate Write inputs. When the next clock pulse arrives, the data will be written into the selected register (s).

Let's try a data transfer from register A to register C in Fig. 7. First, place A's Read input at logic 1. Then place C's Write input at logic 1. When the next clock pulse arrives, the contents of A will be copied into C. Register A will continue to retain its data, but the data in C will be lost.

You can use this simple procedure to transfer the contents of register A, B, or C to either or both of the remaining registers. What control inputs would you place at logic 1 to transfer the data word in register C to registers A and B?

The Concept of Control. We're almost ready to see how a microprocessor is put together. First, let's think about the control inputs to the three registers in Fig. 7.

There are nine authorized ways to transfer data among these registers: A into B; A into C; B into A; B into C; C into A; C into B; A into B and C; B into A and C; and C into A and B. A convenient way to categorize these data transfer options is to list them next to the bit pattern required at each of the control inputs as shown in the box on page 124.

Now each of the transfer possibilities is identified by its own binary control word. In a microprocessor, the control words that transfer data between registers and perform many other operations are called microinstructions.

Often it's necessary to make several transfers, one after another, between registers. For instance, one possible sequence using the circuit in Fig. 7 is A into B; B into C; and C into A. From the table above, the microinstructions required for these operations are:

100100
001001
010010

In a microprocessor, a sequence of microinstructions that carries out a specific series of operations like this is called a microroutine.

Microprocessors have a special control section that automatically generates the microroutines necessary to transfer data inside the microprocessor and perform many other operations as well.

The Microprocessor. The function of a conventional digital logic circuit cannot be significantly changed without extensive rewiring. The microprocessor is radically different. It can be made to perform many different functions simply by changing a sequence of binary words or instructions stored in one or more memory chips which are external to the microprocessor.

Its programmable nature makes the microprocessor essentially identical to the central processing unit of a digital computer. Add an external memory chip to store instructions and data, and a microprocessor becomes a microcomputer. Some recent microprocessors include on-chip memory for instructions and data and are called single-chip microcomputers.

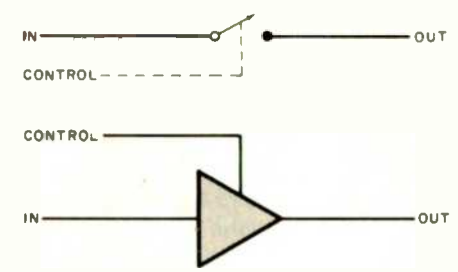
Though a microprocessor can be used as part of a computer, there are numerous, less glamorous but equally important, applications ranging from traffic-light controllers and electronic scales to "smart" test instruments and pocket calculators. In many of these applications the microprocessor's program is permanently stored in a ROM. Several of these types of memories containing different programs can be used with the same microprocessor to accomplish various applications.

Microprocessor Organization. A minimal microprocessor contains a control section, a program counter that steps through the instructions and data stored in an external memory, several data and instruction registers, and an arithmetic logic unit (ALU). One way these circuits can be organized with respect to one another and to both a control and an address/data bus to form an ultra-simple microprocessor is shown in Fig. 8.

There's nothing remarkable or unusual about any of these circuits. What's important is the way they're connected to the two buses. Let's look at some of the operations performed by each of the sections in our basic microprocessor.

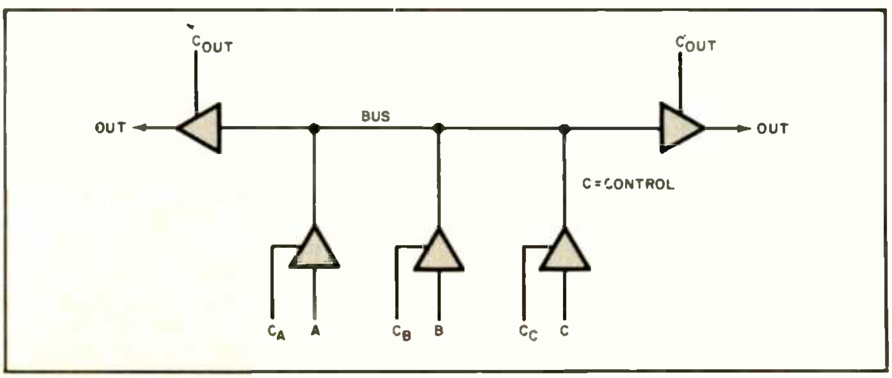
Control Section. The control section is the nerve center of a microprocessor. A typical microprocessor can execute perhaps fifty or more different instruc-

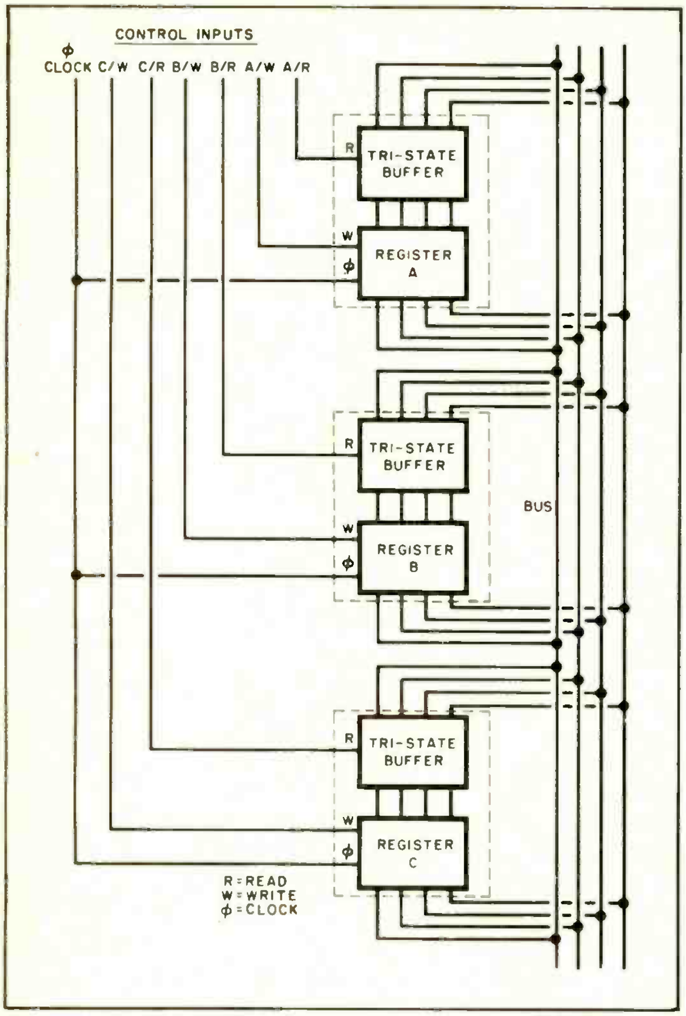
Fig. 5. Simple three-state buffer can be represented by switch as shown at top. Below is its logic symbol and truth table.



CONTROL	IN	OUT
0	0	HI-Z
0	1	HI-Z
1	0	0
1	1	1

Fig. 6. Three-state buffers connected to a common bus. Since data can travel either way, the bus is called bidirectional.





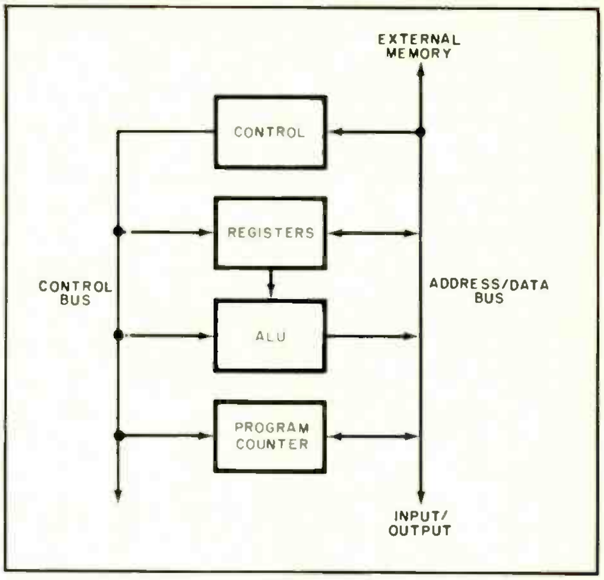


Fig. 8. Organization of a basic microprocessor. The control section is the nerve center. Counter sequences through a program one step at a time. Register is for storage, and ALU performs arithmetic or logic operations.

Fig. 7. Three 4-bit registers connected to a common 4-conductor bus through 4-bit three-state buffer. The three control inputs are: Read, Write, and Clock.

tions in almost any combination or sequence. (We'll look at some representative instructions later.) It's the role of the control section to fetch instructions one at a time from the ROM or RAM program memory connected to the microprocessor's address/data bus, decode and then execute them with a sequence of microinstructions; after which, it fetches the next instruction.

Program Counter. The program counter keeps track of a program that's being executed. It's simply a counter whose outputs are used as address inputs to the external memory containing the program and data being processed by the microprocessor.

The program counter and the address/data bus control how many words of external memory can be accessed by a microprocessor. Thus a 4-bit program counter can access a 16-word (2^4) memory. An 8-bit program counter can access 256 (2^8) words, and a 16-bit program counter can access 65,536 (2^{16}) words.

Normally the program counter sequences through a program one step at a time in ascending numerical order. Certain instructions, however, can load the program counter with a new data word which it will then use as the next external memory address. This allows the microprocessor to *branch* or *jump* to different parts of a program or loop through a specified section of program more than once.

Branching and looping can be unconditional or conditional. In the latter case, the program counter will receive a new address *only* if a specified condition is met (for example, a negative result of a previous calculation, etc.).

Registers. A microprocessor has several registers for the temporary storage of data, addresses, and instructions. The memory address register stores the address from the program counter until it's time for the control section to fetch a new address. The instruction register stores the instruction fetched from the external memory until it's been executed and a new instruction has been fetched. Various data registers store words awaiting further processing and act as output buffers.

The accumulator register stores intermediate and final results of operations by the ALU. It may have the ability to increment (add 1 to) or decrement (subtract 1 from) a word as well as shift a word left or right a bit at a time. Often data entering and leaving a microprocessor must pass through the accumulator. Therefore it's the most important register in a microprocessor.

Arithmetic Logic Unit. The ALU can perform arithmetic or logic operations on one or two data words. The accumulator is closely associated with the ALU. Typically, the accumulator supplies one of the words to be processed by the ALU. The result is then fed from the ALU's output back to the accumulator over the address/data bus.

MPU Programming. So far we've emphasized the *hardware* aspects of microprocessors. Hardware, of course, is important; but without software, the programs that tell a microprocessor what to do, a microprocessor is of no practical use. You might say software is to a microprocessor what recipes are to a cook.

A microprocessor has dozens of instructions in its instruction set, and it's the job of the programmer to combine some or all of them in a way that will cause the microprocessor to accomplish a given task.

One common microprocessor instruction is load the accumulator or simply LDA. This instruction loads the accumulator with the data word which follows it in the program. Incidentally, LDA is an abbreviated form of the instruction called a *mnemonic* by programmers.

Other common microprocessor instructions are JMP (jump unconditionally to the specified address); JZ (jump *only* if a zero is loaded in a special flip-flop); JP (jump *only* if the result of an operation is positive); CLA (clear the accumulator to 0); ADD (add contents of accumulator and data register and place sum in accumulator); MOV (move data from one specified register to another); RAL or RAR (rotate the bits in accumulator left or right); and HLT (halt the microprocessor).

Of course these instructions are only representative of those available with real microprocessors. Nevertheless, they provide an excellent illustration of the computer-like power of the microprocessor.

Now we'll introduce PIP-2, a simple *P*rogrammable *I*nstruction *P*rocessor that demonstrates many fundamentals of microprocessor operation. We'll study PIP-2's operation in detail and learn how to program it. ◇

PART 4. PIP-2
AN ULTRA-SIMPLE EDUCATIONAL MICROPROCESSOR.

Micro-PROCESSOR MICROCOURSE

IN PART 3 of this series, we learned about semiconductor memories and how three-state logic allows data transfer over a bidirectional data bus. We also looked at the basic organization of a microprocessor.

Now we're going to meet PIP-2, a very simple, 4-bit educational microprocessor. Though PIP-2 is not as powerful as the 8080, Z80, 6502 and other real-world microprocessors, it illustrates some of the more important operating features of microprocessors.

Introducing PIP-2. *PIP* is an acronym for Programmable Instruction Processor. PIP-2 is a simplified successor to PIP-1, an educational computer described in detail in *Understanding Digital Computers*, a book published by Radio Shack.

While PIP-2 is simple, it has many of the elements of a sophisticated microprocessor. For example, PIP-2 contains a built-in program memory—so it really qualifies as a *microcomputer*. Since it also contains a microprogrammable control ROM, this means that its instruction set can be revised, or replaced, by entirely new instructions.

PIP-2's Organization. A block diagram of the major components of PIP-2 is shown in Fig. I. As you can see, PIP-2 is a bus-organized microprocessor. All of its sections are connected to a 4-bit bidirectional bus which permits data *and* memory addresses to be transferred from one section to one or more other sections connected to this bus.

Remember from Part 3 that only *one* section can read data onto a bidirectional bus at any one time. PIP-2 meets this operating restriction by employing three-state outputs on all sections designed to read data onto the bus. This isolates the output of those sections from the bus until they are activated (one at a time) by an appropriate enable signal from PIP-2's control section.

Let's now take a look at each of the sections in PIP-2.

Input. A row of four toggle switches, a LOAD switch and an INITIATE switch comprise PIP-2's INPUT. All these switches are shown in Fig. 2, a front-panel arrangement that allows PIP-2 to be used like a microcomputer.

Applying power to PIP-2 automatically clears the A and B registers, the program counter and the program memory to all 0's. This permits a program to be loaded into the program memory by simply switching in a binary instruction or data word and pressing the LOAD switch.

Up to sixteen 4-bit instructions and data words can be loaded into PIP-2's program memory. After the program is loaded, the program counter is cleared to 0000 by pressing the INITIATE switch. This returns the program counter to the first memory address in the program memory in preparation for running the program.

Program Memory. This is a 64-bit read/write memory (RAM) organized as sixteen 4-bit words or "nibbles." The RAM has a three-state output to keep its instructions and data isolated from the address data bus until they're needed.

The program memory has a single control input, RAM/R (R = read). When RAM/R is low, the three-state output is enabled, and the RAM reads the word addressed by the program counter onto the address data bus. When RAM/R is high, instructions and data can be loaded into the RAM.

Program Counter. This is a 4-bit binary counter. PIP-1 and many real microprocessors have a special memory address register that saves the contents of the program counter until it's time to advance to the next memory address. In PIP-2, the program counter doubles as a memory address register.

The program counter has three control inputs. A "low" that's supplied to PC/C by pressing the INITIATE switch clears the counter to 0000. The rising edge of a pulse applied to PC/I incre-

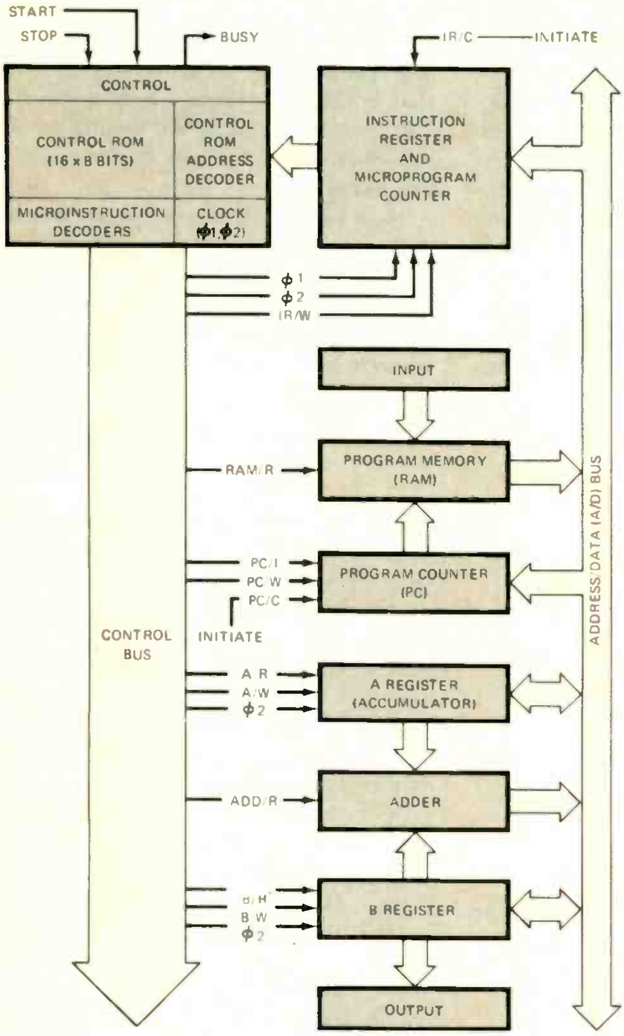


Fig. 1. Block diagram showing organization of the PIP-2 microprocessor.

ments the program counter to the next higher count. A low at PC/W (W = write) writes any data on the address data bus into the program counter. This is a valuable feature since it means the program counter can branch to any address in the program memory.

A and B Registers. These are standard 4-bit data registers with three-state outputs. Each has two control inputs and a clock input (ϕ 2).

When A/R or B/R is low, data is read from the selected register onto the address/data bus. When A/W or B/W is low, any data on the address/data bus is written into the selected register when the next clock pulse (ϕ 2) arrives.

Adder. This is a 4-bit combinational logic circuit that continually sums the contents of the A and B registers. The sum is isolated from the address/data bus by a three-state buffer. When ADD/R is low, the buffer is enabled and the sum is placed on the bus.

Output. PIP-2's output consists of four light emitting diodes (LED's) that continually show the contents of the B register. It's possible, of course, to connect external devices in place of the LED's. A 4-line to 16-line decoder, for example, would permit PIP-2 to control any one of up to sixteen external devices.

Control. This is the electronic nerve center of PIP-2. Control fetches instructions from the program memory and executes them one by one under the perfectly synchronized control of timing signals (ϕ1 and ϕ2) produced by the clock.

Control consists of a 128-bit ROM organized as sixteen 8-bit bytes, an address decoder, several microinstruction decoders and a two-phase clock. PIP-2's instruction register doubles as a microprogram counter and is so closely associated with control that it can be considered part of it.

Control's ROM contains a sequence of from one to five microinstructions for each of the various microroutines necessary to execute PIP-2's six instructions. As you'll recall from Part 3, individual microinstructions implement simple operations such as data transfers from one register to another, etc.

PIP-2's Instruction Set. PIP-2 can process six separate instructions. Each instruction is identified for humans by a type of shorthand called a *mnemonic* (memory aid) and for PIP-2 by a 4-bit nibble called an operation code or in simple terms an *op-code*.

Some of the instructions require only one program memory address, while others are followed by a data word. These latter instructions require two program memory addresses and are called memory reference instructions. For example,

0001 (LDA)
1111 (data)

is the format for a memory reference instruction that loads the A register (LDA) with the data word 1111.

Shown in the box below is a table that summarizes PIP-2's instructions set. These instructions are so simple that they really need no further explanation. It will be easier to apply them in actual programs, however, if we know something about how and why they're used. Therefore let's discuss the instructions one by one.

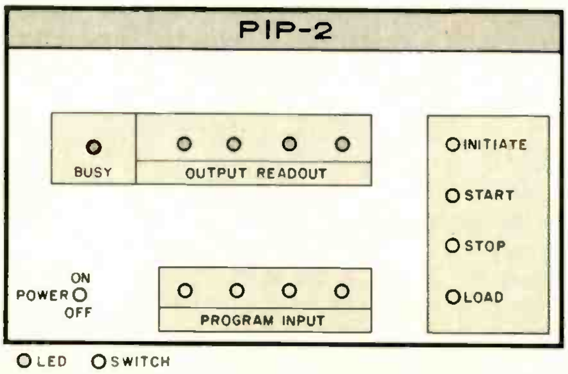


Fig. 2. Front-panel arrangement to facilitate operation of PIP-2.

PIP-2's INSTRUCTION SET			
Mnemonic	**Op-Code**	**Nibbles**	**Operation**
NOP	1111	1	no operation.
LDA (nibble)	0001 (xxxx)	2	load A with next nibble.
ADD	0101	1	add A + B; store sum in A.
JMP (address)	1000 (xxxx)	2	jump to address in next nibble.
MOV	1011	1	move A into B; save A.
HLT	1110	1	halt the microprocessor.

NOP. Pronounced "no-op," this is a do-nothing instruction with several valuable applications. You can use a NOP or two to reserve space in a program for an instruction or two you might want to add later. And you can use NOP's to replace instructions you remove from a program without rewriting the program. Finally, you can use NOP's to add a predictable time delay to a program. This is handy for calibrating a program that loops through a cycle of instructions again and again to act like a timer.

LDA. This memory reference instruction (load A) loads the A register with the data nibble in the next program memory address. It is used to temporarily store a nibble for addition or later transfer to the output or program counter.

ADD. This single-step instruction initiates a string of five microinstructions that *adds* the contents of the A and B registers and places the sum in the A register. It is used for ordinary addition, and to increment the nibble in the A register by some specified number (often 1). Incidentally, ADD uses the A register like the accumulator register found in real microprocessors.

JMP. This (jump) is a very powerful instruction that orders the program counter to branch (or jump) to the address in the program memory specified in the following nibble. JMP is used to set up a *loop*, a program or section of a program that continues to execute again and again until PIP-2 is halted by pressing its STOP button.

MOV. This register-transfer instruction has several applications. As an output instruction, it allows PIP-2's operator to see the contents of the A register on the LED readout (output). It also allows you to accomplish the equivalent of a LDB (load B) instruction by preceeding it with LDA (load A). And, it lets you double a number by following it with an ADD.

HLT. This instruction (halt) is placed at the end of all PIP-2 programs. It disables the clock in the control section, thus preventing PIP-2 from executing any additional instructions.

How to Program. Let's write a simple program for PIP-2 that continually increments the number in the A register by one and displays the updated count on the LED readout of the output. Here's the program:

Program Memory Address	Mnemonics/Data
0000	LDA
0001	0001
0010	ADD
0011	MOV
0100	JMP
0101	0000
0110	HLT

It's easy to see how this program works. When PIP-2 is started, both the A and B registers are cleared to 0000. This means that the first three instructions load 0001 into A, add A to B and store the sum (0001) in both A and B. JMP loops the program back to line 0000 for another cycle. LDA replaces the contents of A with 0001 first. Register B also contains 0001 so ADD gives 0010. The sum, 0010, is moved into B and displayed on the readout.

Again, JMP loops the program back to line 0000 and the process continues. The result is that the readout flashes a binary count of 0000 to 1111 and continues repeatedly until PIP-2 is halted.

This program is nothing more than a software version of an ordinary 4-bit counter. That alone is not very impressive since PIP-2 already contains *two* such counters in its hardware, the program counter and instruction register.

What's significant is that this simple program can be easily modified to implement *any* count increment from 0000 to 1111 by simply changing the data nibble following LDA! While this can be accomplished with some relatively simple hardware, PIP-2 performs the task after only a few seconds of software modification. This nicely illustrates the amazing versatility of using a microprocessor to simulate many different hardware functions with the help of software.

Running the Program. The simple counter program we've been discussing is called a *source program* since it's written using the mnemonics of the various instructions. Before it can be loaded into PIP-2's program memory, it must be converted to an *object program*.

An object program is written using the binary numbers a microprocessor understands. Sometimes it's called a *machine language program*. All that's necessary to generate the object program for our software counter routine is to substitute the appropriate op-codes for the mnemonics in the source program with the help of the table showing PIP-2's instruction set. Here's the machine language result:

Address	Source Program	Object Program
0000	LDA	0001
0001	0001	0001
0010	ADD	0101
0011	MOV	1011
0100	JMP	1000
0101	0000	0000
0110	HLT	1110

After the object program is compiled, it's a simple matter to load it into PIP-2's program memory. First, the power switch is turned on. This automatically clears all of the program memory, registers and counters to all 0's. Then the first object code nibble in the program (0001) is switched in via the front panel switches (a switch is 0 in the down position and 1 in the up position) and the LOAD switch is pressed. This action loads the nibble 0001 into the 0000 address of the program memory and automatically advances the program counter to the next address.

The remaining nibbles are loaded one by one until they are all stored sequentially in the program memory. Then the INITIATE switch is pressed to return the program counter to the 0000 address of the program memory.

Now all that remains is to press the START switch. This causes control to fetch the first instruction from the program memory, load it into the instruction register, decode it and execute it. The program is processed in this manner one step at a time, because the output will display the updated contents of the B register.

Incidentally, if the clock speed is more than about a hundred Hz, the count displayed on the readout will blur into a continuous 1111. Since the clock of most real microprocessors runs at a MHz or more, time delay loops must be added to their programs that are intended to display data to be viewed by an operator.

Other PIP-2 Programs. Though PIP-2's instruction set is a very primitive one, it is possible to write a number of different programs with it. The following example gives a source program that adds two numbers and then displays their sum:

LDA
(first number)
MOV
LDA
(second number)
ADD
MOV
HLT

Here's a source program that doubles a number:

LDA
(number)
MOV
ADD
HLT

And here's a program that counts by two's:

LDA
0002
ADD
MOV
JMP
0000
HLT

Programming Real Microprocessors. Real microprocessors include dozens of instructions in their instruction sets. A typical microprocessor, such as the 6800 or 8080, would have instructions that can accomplish any of these tasks:

- Moves data and addresses between registers.
- Shifts and rotates the bits in a data word.
- Performs various arithmetic and logical operations.
- Branches conditionally or unconditionally to any part of a program or to a subroutine.
- Makes various logical comparisons.
- Increments or decrements the contents of a data register or memory address.

Real microprocessors also have special instructions that may be unique to a particular family of microprocessors. For example, some microprocessors feature various instructions for accepting data from outside circuits while other units provide built-in decimal arithmetic capability.

Programming real microprocessors can be both tedious and time consuming, but most people can learn to write simple programs with a little practice and some hands-on experience with a microprocessor using a keyboard (best) or toggle switch (OK) input. Of course, numerous microprocessor programs have already been published in books and articles; and as time goes by, the number of available programs will multiply. ◇

Choosing a Computer for a Very Small Business

BY JOHN ZITZ*

THE US GOVERNMENT identifies a *small* business as one that employs up to 250 people and has an annual gross income of up to $5-million. However, small businesses that can use computers to advantage may be much smaller than that, ranging down to a single user in a part-time business operation. These types of operations are often called "very small businesses."

System cost, naturally, plays an important role. An enterprise grossing $50,000 yearly cannot afford a $20,000 computer or its equivalent in time-sharing systems. Like any capital investment, a data-processing system should be justified by the return it can be expected to produce. Experience has shown that a single computer and its operator can do the work of several people, either saving the cost of some salaries and benefits or freeing personnel for other tasks. In some cases, the computer will have enough extra data-handling capacity to allow the business to expand with little or nothing in the way of increased computing costs.

Perhaps more important, the computer is very fast and can keep the businessperson informed about the status of affairs today, not the way they were last week. Further, since the computer eliminates many hours of manual clerical work and can deliver its output in a compact precise form that obviates a good deal of "paper shuffling," it can create more time for the research, decision making, and creativity that are the real essence of an entrepreneur's function.

Besides its obvious functions in accounting, inventory and production control, and the like, a computer can also—with the right software—handle secretarial functions such as appointment planning. Mailing lists, telephone files, library catalogs, and similar collections of data can be created, alphabetized, updated, and printed as desired. With the addition of a text-editing program a computer can process correspondence. Form letters, for example, can be written, recalled, and personalized with great facility.

Requiring no rest or sleep and only occasional maintenance, a computer can be used 24 hours a day; even when the business is closed. Both hardware and software are available to let the computer "watch over" sensitive systems such as refrigerators, air conditioners, water pumps, etc. It can also sense intrusion, fire, smoke and other emergency conditions and perform some predetermined function when an alarm is activated. Communication with the computer at any time is a possibility, even from remote points across the country using a telephone attachment called a modem. This means that salesmen can communicate orders, or get product information over the phone line when they desire. Businessmen who generate new ideas at night can, via a terminal and modem at home, put these into effect or at least record them while they are fresh. It is even possible to run an enterprise by "remote control."

The System. Just as vehicles, regardless of their make or model, are pretty much the same under their metal skins, computers are too. The former have engines, suspensions, transmissions, etc., as main working parts while the latter have memory, central processor units, input/output modules, interfaces, etc.

Vehicles can be optimized for business or pleasure depending on the options selected, and the same is true of computers. For business use, you need a machine that has enough computing power and enough options to handle both your present and anticipated future requirements. This is why it always pays to take a look at *all* the options for a particular computer, since as your business grows, you may require functions not needed at the present.

A few years ago, computer enthusiasts who wanted to use a "hobby-type" computer for business would explore what microprocessor was being used, what type of bus was offered, and so on. The growth of the moderately priced computer market has changed all that. Consequently, software is *the single overriding consideration* in buying a business-oriented computer today.

For most applications, the "computer" will be a keyboard, video display and printer, all attached to a small enclosure in which the actual data manipulations are performed. There may also be another enclosure containing the disk storage system. Sometimes a keyboard and printer or video display are combined in a single unit called a terminal. This can be located near or remote from the computer.

To enable the computer to be used by personnel trained in normal secretarial skills, the keyboard should have a conventional typewriter format, with comfortably spaced and easy-to-the-touch keys. If a lot of numeric entries are to be made, a separate keypad is a definite convenience.

Quality of the video display is also important as it will determine the extent of eyestrain (which may result in possible entry or reading errors) if the display is used for extended periods. The usable

PCE Microcomputer Systems, Sacramento, CA.

screen should measure at least 12" diagonally and have a contrast that is comfortable to the eyes. The characters should be sharp and free from glare. They should be crisp from edge to edge across and from the top to the bottom of the screen, and should exhibit very little nonlinearity. Dual-brightness or inverted (black-on-white instead of white-on-black) characters are useful for special attention-getting displays, as is the capability of rendering color. The system should display at least 80 characters on 24 lines for business applications. Many small computers project only 16 lines of 64 characters per line—somewhat limiting for ledger and similar entries.

The printer, or hard-copy device, should be selected for its type face, speed, and noise level (some are quieter than others). It should be of sturdy construction and have adjustable columns for different width paper. The paper should be tractor or pin fed from the carriage to keep the paper secure in its place and free from misalignment—a necessity for automatic printing of checks and for keeping columns in proper vertical order.

Printer prices increase directly with the speed and quality of the print, and it is up to the purchaser to determine just what he wants. The need for upper- and lower-case characters and for multiple copies is a consideration, too.

The disk system is also determined by the amount of data you expect to store. Obviously, the larger the disk system, the more data can be stored. Keep Parkinson's Law in mind—data expands to

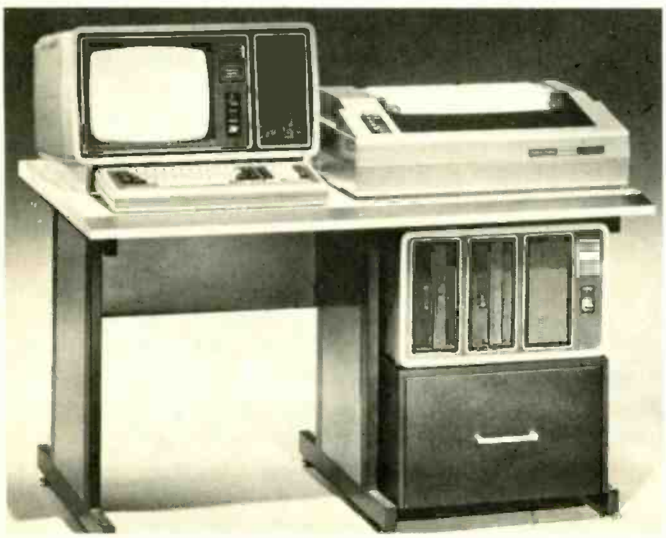
Apple II Colorgraphics Computer.

fill the available disks. Small (so-called 5" disks) can hold up to 90K bytes of data (enough for several hundred inventory entries), while the so-called 8" disk can support up to 240K bytes of data. There are dual disk systems that increase data storage in one package, and there are dual- and quad-density and double-sided disk systems that maintain package size but greatly increase storage capacity. If your business is large enough, it may even pay you to take a look at the more expensive hard disk systems that can hold many millions of bytes of data. If at all possible, a business person should have at least a dual-disk system since it pays to make a backup copy of a completed disk for emergency use.

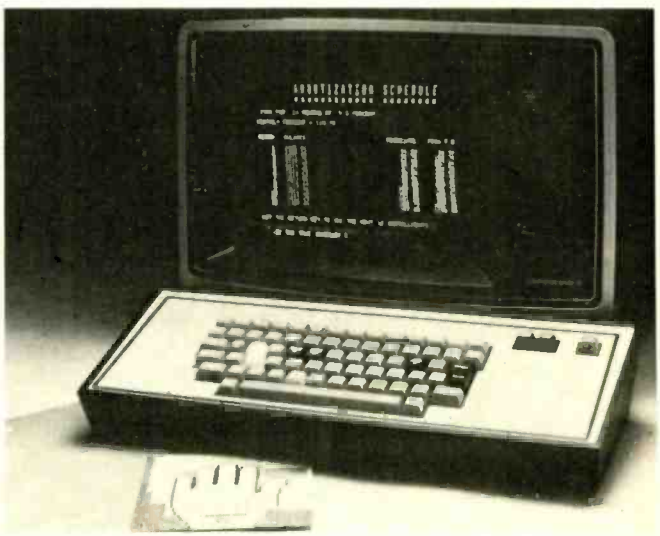
Since the most important consideration is software, it pays to make certain that the computer system you choose has a good selection available for it. In some cases, special "emulator" programs allow one machine to mimic another for which a desired item of software is available. However, this approach lowers the effective operating speed of the processor to a mere fraction of normal. Clearly, a modest (less costly) installation humming along with efficient software is preferable to a fancy one that limps because its software pinches. If it would be beneficial for your purposes to use COBOL or FORTRAN instead of BASIC, be sure your system is compatible with these languages.

Cost And Operation. The cost of a computer system is not just what the store charges you to take the package home. Maintenance and later expansion, for example, are obvious sources of additional cost. The great nemesis of all system planning is changing needs. A system that can be altered to suit all contingencies will cost more than one that is specialized, but it may be worth the difference in the long run. The choice between the two depends on the nature of your business. We will try to develop here rational guidelines that, taking the special nature of computers into account, will help to minimize costs.

"Off the Shelf" or "Custom". One attractive and low-cost approach is to buy standard hardware and software packages. If your application is commonplace, you may be able to purchase application programs that have already been written and field-tested. Packages exist for inventory applications, payroll,



Radio Shack TRS-80 Model II Microcomputer with Line Printer III, External Disk System.



Compucolor II Model 3 Computer with color video display.

general ledger, accounts/payable and receivable, etc. With good knowledge of your business requirements, you could purchase a system that is optimized for the packages you need, while allowing for system integration and expansion.

To have custom software written specifically to your needs by a reputable analyst and then have a hardware system implemented around that software, is another possible alternative. The pitfall is that the exclusivity of your system may inhibit changes in the future should they become necessary.

A middle path between these two extremes is to purchase a system that is mostly "off the shelf" and make minor adjustments as necessary. Many private vendors will have the resources to make these modifications if they are not too extensive and may even include them in the overall price of the system. In any case, all software and hardware modification should be in the hands of reliable consultants. A largely "off the shelf" system with canned software included in its price would range from about $4,000 to $8,000, depending on the peripherals put into the final system.

One difference between a "business computer system" and a "computer system that means business" is in the planning done in anticipation of breakdown and further expansion. The usual vendor warranties are enough to absorb the cost of initial problems until the system is finally "up and running." The reliability of the electronic technology that goes into computers is such that a business computer under normal use should not

Heathkit H11A 16-bit Computer has provisions for business peripherals.

encounter a debilitating breakdown in well over a year of use. Even then, the most common breakdowns in a microsystem are not electrical but mechanical. Switches, motors, drivers, actuator arms, and wheels fail far more often than electronic components.

Superficially attractive as all-in-one computers are, they are not for business. When a single functional part of an all-in-one computer fails, the whole machine goes down and, in many cases, must be sent to the factory for repair. The independent modular approach allows the offending module to be removed and repaired, often while a temporary replacement is substituted. This keeps the system reliability high despite the failure of individual modules. In the case of duplicate systems in one installation, modules can be temporarily "swapped" until replacements arrive.

External Problems. One of the hidden causes of computer component failure is noise transients and voltage spikes from electrical equipment such as motors, tools, etc., that are passed to the computer via the power lines. Not only can such "hash" and power-line surges damage components, they can also interfere with computer operation. It is essential that a well-engineered computer system have hash and power surge suppression built into its power supply. This can eliminate considerable hidden cost in operation.

Options. Another interesting power-supply option protects your computer against momentary power-line "blackouts". The capacitors in a good heavy-duty power supply can maintain their charge for about a fifth of a second after the mains go down. This is time to kick in a back-up power supply without losing data or causing the system to "crash". An uninterruptable power supply can be added to a system fairly inexpensively and may, once in a while, save the day.

What About Protecting the Data? Computer failure can wipe out valuable data. However, if one takes the normal precautions of keeping backup disks and tapes, the likelihood of a serious setback is reduced. Cassette tapes and recorders are relatively cheap compared to disks and disk drives and are a cost-effective means of data protection. The high access speed of the disk is not a factor when all you are looking for is long-term archival storage. A small routine for transferring the data stored on a disk to a cassette is not difficult to imple-

Commodore PET 2001 Series Professional Computer.

Exidy Inc. Sorcerer Computer with dual-disk drive and video display.

Ohio Scientific C8P DF System—Challenger 8P Computer, dual-disk drive, terminal, monitor, peripheral control devices.

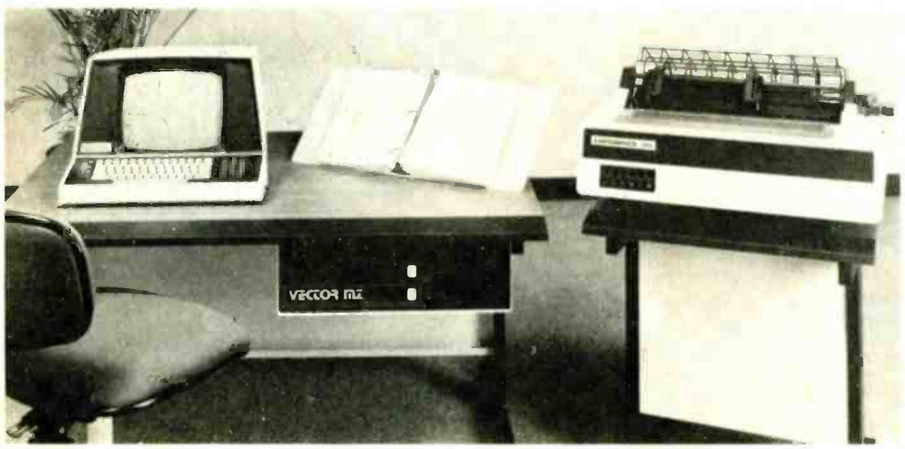
ment and might even be part of the DOS (Disk Operating System) provided with the computer.

Security. Principally, this involves protecting the data physically from theft, destruction or tampering. Such protection is not difficult to implement if the entire system is in your premises, where access to it can be controlled. But what if data must be transmitted by telephone, other hard-wire lines, or mail?

Hardware and software for encrypting data have just begun to appear on the market and will probably be included in total systems in the near future. For example, special chips which can encode data at high speeds, could be incorporated as part of the input-output interfacing of a data-transmission module. Here is another instance in which the modular approach to the computer design facilitates expansion of an existing system.

When To Buy. Is there a "right time" to buy a computer? Should the small business lease a computer, timeshare on a larger computer, or buy one outright? In the past, the high cost of computers and their relative inaccessibility made timesharing at a cost of several hundred dollars per month seem attractive. The low cost of microcomputers today has made this a more dubious proposition. The cost of the timeshare terminal alone is approximately 25% the cost of a microcomputer-based business system. Add to this the monthly cost of computer services and telephone line hookups and the total over a year rapidly approaches the cost of an entire small computer system. And of course, there is no equity.

Timesharing should only be considered when access to a large, computationally powerful computer is needed, as might be the case in engineering or scientific applications or those that generate volumes of statistical analyses. For the standard small-business-scale applications, even where sizable inventory accounting is involved, eight-bit microprocessing is the most cost-effective way to go. In short, for most very small businesses, don't borrow, don't lease—buy! And if you feel that your business is ready for the system, buy now. ◇



Vector Business System—MZ Computer with dual floppy drive, MT Terminal, and Centronics 702 Printer.

NOTICE TO READERS

We consider it a valuable service to our readers to continue, as we have in previous editions of this guide, to print the price set by the manufacturer or distributor for each item described as available at presstime. However, almost all manufacturers and distributors provide that prices are subject to change without notice.

We would like to call our readers attention to the fact that during recent years the Federal Trade Commission of the U.S. Government has conducted investigations of the practices of certain industries, in fixing and advertising list prices. It is the position of the Federal Trade Commission that it is deceptive to the public, and against the law, for list prices of any product to be specified or advertised in a trade area, if the majority of sales of that product in that trade area are made at less than the list prices.

It is obvious that our publication cannot quote the sales price applicable to each trading area in the United States. Accordingly, prices are listed as furnished to us by the manufacturer or distributor. It may be possible to purchase some items in your trading area at a price that differs from the price that is reported in this edition.

The Publisher

ELECTRONIC EXPERIMENTER'S HANDBOOK 1981

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