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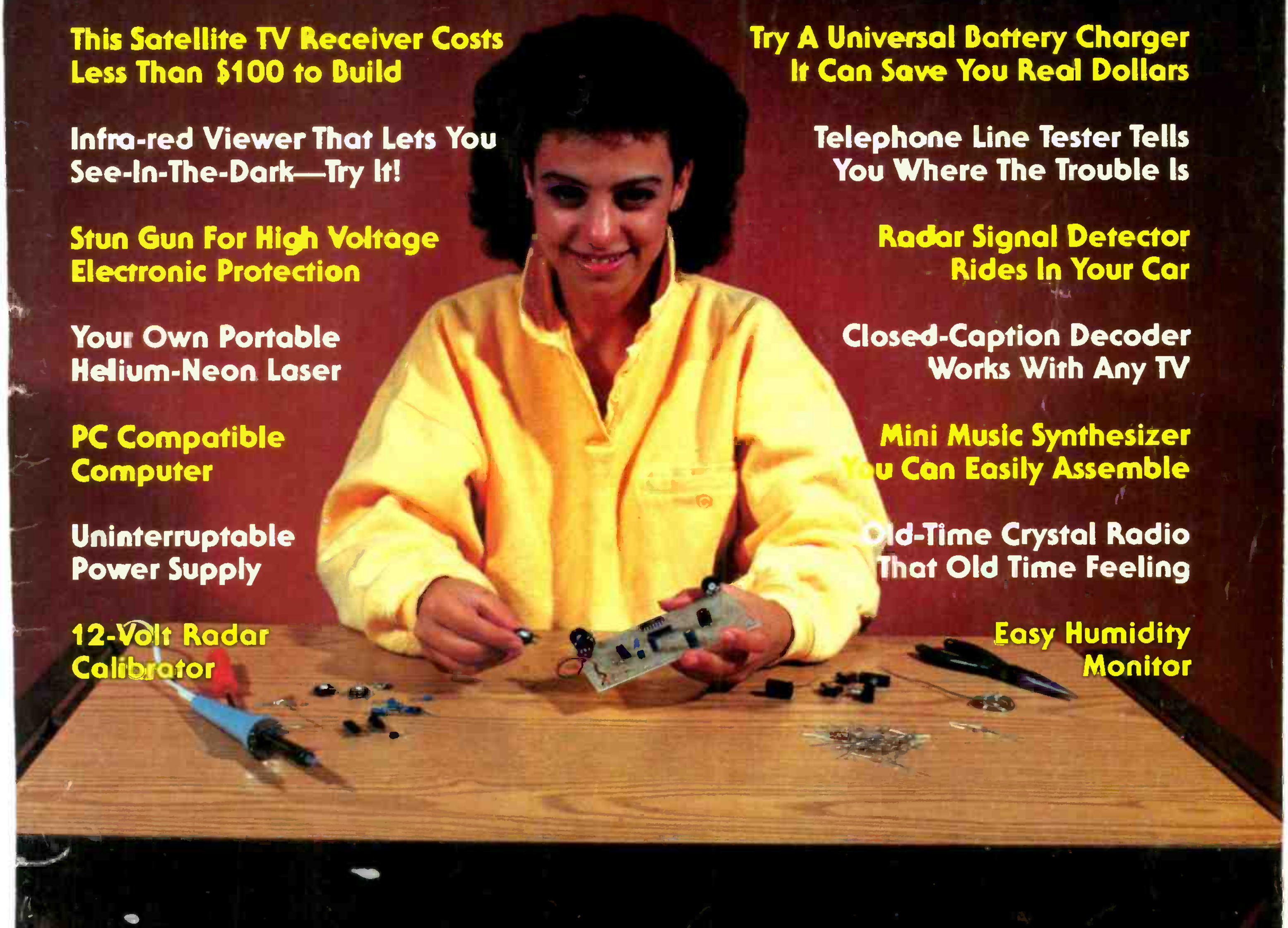

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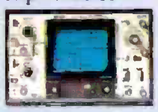

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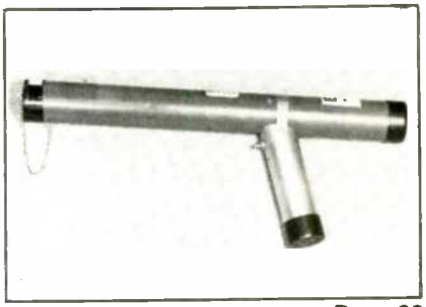
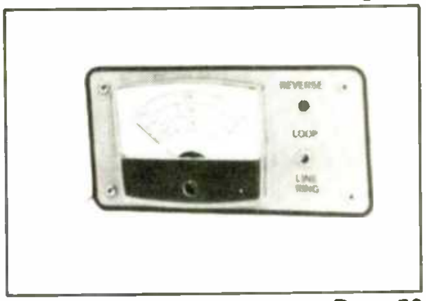
CONTENTS

NEW IDEAS

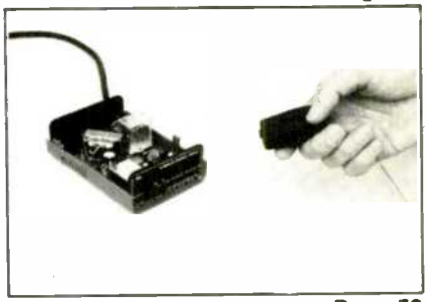
Necessity may be the mother of invention, but our inventive readers constantly submit the fruits of their labors. We frequently publish these *New Ideas*, and what better way to complete this book than with an assortment of those we consider to be the best!



Page 38



Page 50



Page 59

Page 63

Page 85

EDITORIAL

1987 ELECTRONICS EXPERIMENTERS handbook

ABOUT THIS BOOK

To give you some small insight to the editorial process, picture an editor cutting and pasting articles from two years' worth of RADIO-ELECTRONICS Magazines. And when—finally—the job is complete, the proof-reading starts. That's when it is discovered that what appeared to be a five-page article finishes by saying "Continued next month..." Now you face a choice: Either replace that article with a *real* five-pager, or remove the next article and put in the conclusion of the first. But now the job is done.

Know that this book has been carefully gone over, the articles included herein have been read *several* times, that the desk-reference set has been consulted in detail so that any reported errors have been corrected, that the several editors who worked on the various pieces have affirmed that there are no errors, and finally, the Letters-To-The-Editors columns have been carefully consulted to reveal any additional errors that may have been reported.

In other words, every possible source of a mistake has been covered.

But also know that the mortality rate among electronic firms is fairly high. Before attempting to build any project, write to the various manufacturers to make sure that parts are still available and that prices have not changed since the original article first appeared.

The only thing that remains to be said, is that a great deal of time and effort went into the preparation of the book you now hold in your hands. We sincerely hope that it is all you anticipated it to be when you purchased it and would like to hear both your plaudits and your complaints. Do write and let us know.

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ON THE COVER

As it happens, young ladies are as capable with soldering irons as men are. They have equal capability to understand the principles of electronics, and it seems they can derive as much pleasure and satisfaction in the completion of a complex construction project as anybody else!

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Voltage Coefficient (DC): Negligible
Aging Rate: Negligible
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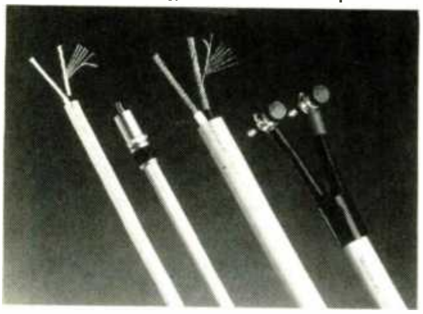
NEW PRODUCTS

Audiophile Cables

Kicking off the Monster Cable line, is the M1 speaker cable. This cable enables a sound system to operate at its top capacity to provide accurate, full-range sound reproduction.

Using the company's *"Microfiber"* dielectric technology and sophisticated winding techniques, signals can travel faster and cleaner, eliminating background noise and improving transient response.



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The M1's winding configuration uses multiple wire gauges for various frequency bands combined in "grouped networks" for improved imaging. While custom lengths can be provided, the cables are also available in 15- and 25-foot pairs terminated with Monster Cable's X-Terminators as well as 125- and 250-foot spools. Pre-cut lengths are available in handsome cases that can be used for storage of audio accessories.

Utilising a three-wire, multiple-gauge network for each conductor, the *Bandwidth-Balanced* design offers absolute coherency of frequency and phase response over the entire musical spectrum. The M1000 interconnect cables will be terminated with RCA gold-plated compression connectors with sliding/locking outer rings for better contact and pull-proof fail-safe reliability.

Speaker cables are priced at $9.00/foot, $400./15-foot pair, $550./foot per 25-foot pair. The interconnect cables run from $9.00/foot to $450.20-foot pair.

For additional information, contact Monster Cable, 101 Townsend Street, SanFrancisco, CA 94107, 415/777-1355.

Active Crossover

Designed to control all aspects of multi-transducer, multi-amplifier car audio systems, the CX0-1 from Harmon Kardon meets many needs in the autosound market.

When an autosound installation is made using products of several manufacturers, the result can be an uncoordinated, makeshift installation. This can result in inferior performance, be time consuming and allow for no flexibility. With the CX0-1, professional or consumer installation is simplified and optimum performance can be realized.

Separate stereo mid and high bands are offered, for both front and rear channels, as well as stereo and mono subwoofer channels. Low to mid crossover frequencies are 80Hz, 125 and 200Hz at 12 dB/octave. The mid- to high-frequency crossover selections are 2.5kHz, 4kHz and 6.3kHz at 12dB/octave. "Flat" settings are available that bypass the active filters and offer flat response.

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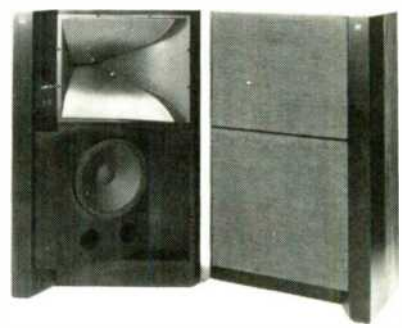
An individual output level control is provided for each of the five bands. The CX0-1 equalizes where it has always been needed in the auto environment, the low end and the low-midranges. A "cut" control at 200Hz is offered to cancel resonances that may be created by the car interior.

The CX0-1 has unity gain and zero insertion loss. With all output level controls located in the final stage, you get filtering and fidelity enhancement with the highest internal signal levels resulting in the best possible signal-to-noise ratio.

The unit is priced at $250. For additional information, write Harmon Kardon, 240 Crossways Park West, Woodbury, NY 11797.

Home Theater Speakers

People listening anyplace in a room will have the sound arrive simultaneously and with equal volume. Used in conjunction with a video system, the sounds will appear to be coming directly from the screen.



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Called *Project Everest*, this three-way speaker design is comprised of a 15-inch, low-frequency transducer in a vented enclosure, a JBL defined coverage horn loading a compression driver for the mid-frequencies and an ultra-high frequency slot-loaded ring radiator. The system is designed in mirror-imaged pairs, with specific right and left channel enclosures.

The defined-coverage horn offers uniform dispersion characteristics for frequencies between 850Hz and 7500Hz with the effect of widening the centered stereo

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image of perception. Because of the controlled driver dispersion, room placement is not at all critical. A listener moving about the room, away from one speaker and towards the other, remains within the direct field of both. The balance of sound between the speakers remains stable over a wide listening area.

Ultra-high frequencies above 7500Hz, are handled by the JBL Pro Division's ring radiator which delivers an extended response to 21.5kHz. The slot loading provides a 140° horizontal dispersion angle which matches that of the midrange horn at the crossover frequency. High-frequency output is user adjustable to complement room acoustics or personal taste.

Project Everest is the most-massively constructed consumer loudspeaker system in JBL's history. Made from high density, compressed wood up to 1½ inches thick in some sections, the design offers proper mounting for the defined coverage horn and sufficient internal volume for the high efficiency and extended low frequency response.

The hand-rubbed, oiled rosewood veneer suits the unit to any room decor. Priced at $9900. per pair, the speaker systems will handle amplifier output powers of 40 to 250 watts per channel, with a nominal 8-ohm impedance. They measure 55⅛ inches high, 36 inches wide, and 20 inches deep. For further information, contact Harman Kardon, 240 Crossways Park West, Woodbury, NY 11797.

Multi-CD Player

Boasting six-disc magazine and single-play tray, this multi-play compact disc player from Pioneer offers random-access programming of up to 80 tracks on eight magazines. The new unit has gold-plated output jacks and digital filtering. The anti-resonance construction is based on a honeycomb chassis and very large insulators.

A random-play feature permits the listener to hear songs in a random order. A large fluorescent display for elapsed/total/programmed time is included. You get two-speed audible search, both forward and reverse.

There are four modes of repeat function, track, disc, magazine and program. Frequency response is 4 - 20,000Hz, +/-0.5dB. The signal-to-noise ratio is better than 100dB and the dynamic range is better than 96dB. Channel separation comes in at over 93dB and the total harmonic distortion measures less than 0.0035 percent. The unit is priced at $599.00

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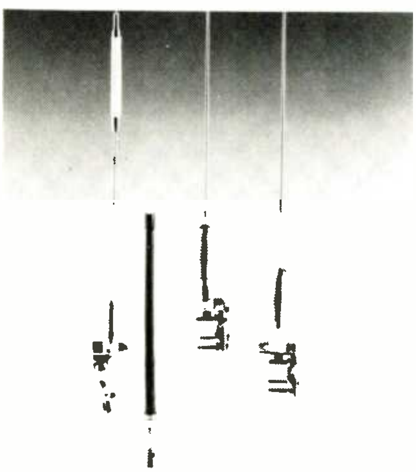
Now if you like those numbers, contact Pioneer at 5000 Airport Plaza Drive, P. O. Box 1720, Long Beach, CA 90801-1720, or call 213/420-5700.

Special CB Antennas

Three specially-designed antennas are offered by Midland. The Model 18-245 is a high-performance co-phased twin antenna that delivers added range. Fiberglass radiators and aluminum mirror mounts make this ideal for trucks and RVs. A pre-wired cable harness and connector are included. Suggested retail is $49.95.



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The Model 18-275 is designed for gutter/luggage rack mounting. It clamps firmly and quickly to vehicles that are so equipped. A pre-wired cable and connector are included, and this unit is priced at a suggested retail of $24.95.

The new Midland "Rubber Duck" flexible antenna, Model 18-253, is designed for use with Midland portable Models 75-710B, 764B, and 790. The Rubber Duck mounts on the existing telescoping antenna base and provides excellent performance, safety and convenience. Suggested retail is only $19.95.

If you'd like additional information, please write to Midland International, 1690 North Topping, Kansas City, MO 64120, or call 816/241-8500.

Hot Speakers

Boston Acoustics recently announced improved versions of their popular home loudspeakers. The A70 series II bookshelf speaker and the A150 Series III floor-standing unit. Both speakers feature new drivers designed and built in the United States by B. A.

CIRCLE 55 ON FREE INFORMATION CARD

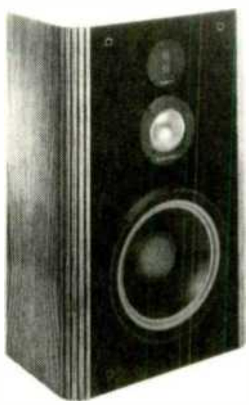
The A-70 Series II is a two-way speaker with woofer, crossover and bookshelf design. The eight-inch woofer uses a polypropylene cone, with more accurate response through the operating range. The tweeter is the B.A. CFT 1-inch dome. Suggested retail price is $300 pair.

The A150 Series III is a floor-standing unit with an all-new driver complement. The three-way system features a ten-inch woofer, 3½ inch midrange, and a CFT 1-inch dome tweeter. Suggested retail is $550.00 per pair.

For additional information, contact Boston Acoustics, 247 Lynnfield Street, Peabody, MA 01960 or call 617/532-2111.

Multi-Driver Speakers

The new-generation Kappa Series from Infinity Systems are finished in hand-rubbed, oiled oak. The series consists of three models; The 12-in. three-way Referance Standard 7 *k*, the 12-in., four-way Reference Standard 8 *k*, and the 12-in. five-way, dual woofer Reference Standard 9 *k*. Each speaker uses a newly-developed cast frame woofer with a cone molded from polypropylene and graphite fiber. The increased stiffness-to-mass ratio of the cone improves bass response.



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Both the 8 *k* and 9 *k* contain the Polygraph *k*, a five-inch dome-shaped driver optimized for 80 Hz to 500 Hz.

The midrange driver, a three-inch polydome *k* is used in all three speakers. It features flat wire, edgewound voice coils and a polypropylene cone that offers extremely low mass and excellent self damping.

Each model is equipped with the EMIT *k* tweeter. The new tweeter's diaphragm weighs half as much as its predecessor, and it is surrounded by exotic, rare-earth neodymium magnets.

For frequencies above 10 kHz, the Reference Standard 9 *k* uses a SEMIT™ supertweeter.

The 7 *k* is priced at $599. retail, the 8 *k* at $899., and the 9 *k* at $1199. For additional data, contact Infinity Systems, Inc., 9409 Owensmouth Ave., Chatsworth, CA 91311, or call 818/709-9400.

Compact VHS Camcorder

While the PV-100 camcorder from Panasonic will fit in your hand, it incorporates some astounding new features. These include a high-speed shutter, a low light, high-resolution CCD image sensor, and a piezo zone auto focus system.

CIRCLE 57 ON FREE INFORMATION CARD

The PV-100 uses a compact VHS cassette which is fully compatible with any existing home VHS recorder when the included adapter is used. The cassette provides a full hour of recording time.

An automatic zone focusing system using piezoelectric technology is employed.

For further information, contact Panasonic Company, One Panasonic Way, Secaucus, NJ 07094.

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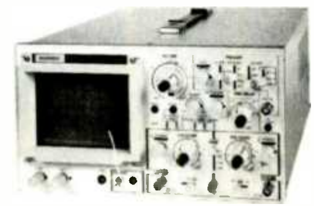

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Lacquered Speakers

This lacquer-finished loudspeaker system from JBL combines classic tradition in design with up-to-the-minute technology. Offering an elegant finish in lacquer instead of wood, the L series speakers are designed to replicate the sound heard in the recording studio. Prices are as follows: For the L20TBQ, $280 each, The L60TBQ is $385, and the L80TBQ comes in at $550 each.

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JBL used pure titanium in the high-frequency transducers. Titanium offers a high strength-to-weight ratio. With a unique process that swirls compressed gasses against a titanium film, the dome needs to be only 25 microns thick, less than the diameter of a strand of human hair. An intricate network of ribs formed into the dome elements eliminates any possible deformation problems.

Crossover in the L series is achieved by high spatial-identification dividing networks. These not only assure smooth driver-to-driver transition, they guartantee proper musical placement.

All the L-Series speakers are finished in European high-quality polyurethane acrylic enamels, as beautiful as they are durable. For additional information, contact Harman Kardon, 240 Crossways Park West, Woodbury, NY 11797.

Public Information Radio

While people are fascinated by the activity on public service bands, the idea of programming a scanner or looking up frequencies in a directory is a turn-off. For them, Regency has developed the Informant INF-5. This user-friendly receiver is factory pre-programmed so it can be operated by anybody with no previous knowledge of scanners.

At the touch of a key, the unit monitors police, fire, emergency or weather broadcasts for a particular state that is four times as fast as other scanners.

A special "weather scan" feature allows it to find the latest weather information from the National Weather Service with a single touch.

CIRCLE 59 ON FREE INFORMATION CARD

This is called the fastest-scanning receiver on the market. Its patented new "Turboscan" technology—a Regency exclusive—allows it to scan public service frequencies at a rate of 50 channels per second, nearly four times faster than competitive models.

Other features include a digital display which shows the state and type of transmission being monitored, a top-mounted speaker, a hold switch to keep the receiver on a single frequency, and a squelch control to reduce background noise. The INF-5 has a suggested retail price of $349.95, and has a one-year warranty. The package includes an AC power-supply cord, telescoping antenna and easy-to-follow instruction manual. Additional information can be had by writing to Regency Electronics Inc., 7707 Records Street, Indianapolis, IN 46226.

Compact Speaker

The MFJ-280 loudspeaker is pegged at a low $18.95. For that price, you get a rugged, compact mobile loudspeaker including a tilt bracket and magnetic base.

The unit comes with a 3½mm phone plug on the end of a long cord. It works well with all four- and eight-ohm impedances and can handle up to three watts of audio. Its dark-gray color goes well with nearly all rigs.

In addition to an unconditional

CIRCLE 60 ON FREE INFORMATION CARD

one-year warranty, the speaker, if purchased from MFJ may be returned within 30 days for a full refund, less shipping charges. To order or get additional information, contact MFJ Enterprises, Inc., P. O. Box 494, Mississippi State, MS 39762. Tel. 800/647-1800, or 601/323-5969. Telex number is 53-4590 MFJ STKV.

Multi-Band Radio

Combining a microcomputer-controlled, PLL quartz-synthesized receiver and a double superheterodyne system, Panasonic has introduced the RF-B60, a compact, multi-band (FM/LW/MW/SW) radio with outstanding sensitivity, stability and selection.

The unit utilises an up-conversion double superhet receiver, providing two IF's to help reduce first and second image interference characteristics while image rejection is reduced by raising the initial IF to 55.845mHz.

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The system offers 36-station preset tuning, allowing instant recall using the corresponding memory recall keys.

Priced at $269.95, the RF-B60 requires 6 "AA" size penlight batteries which are not included. For further information, contact Panasonic Co., One Panasonic Way, Secaucus, NJ 07094.

continued on page 138

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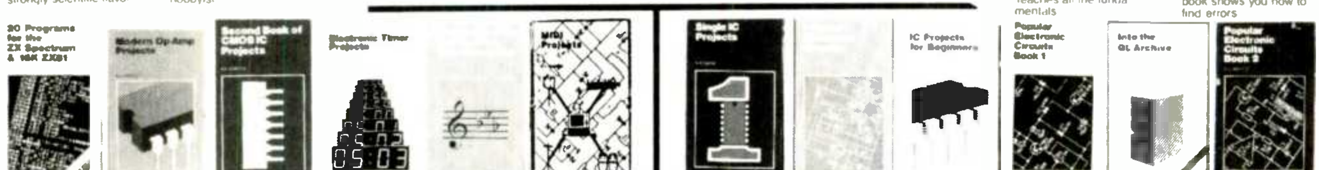

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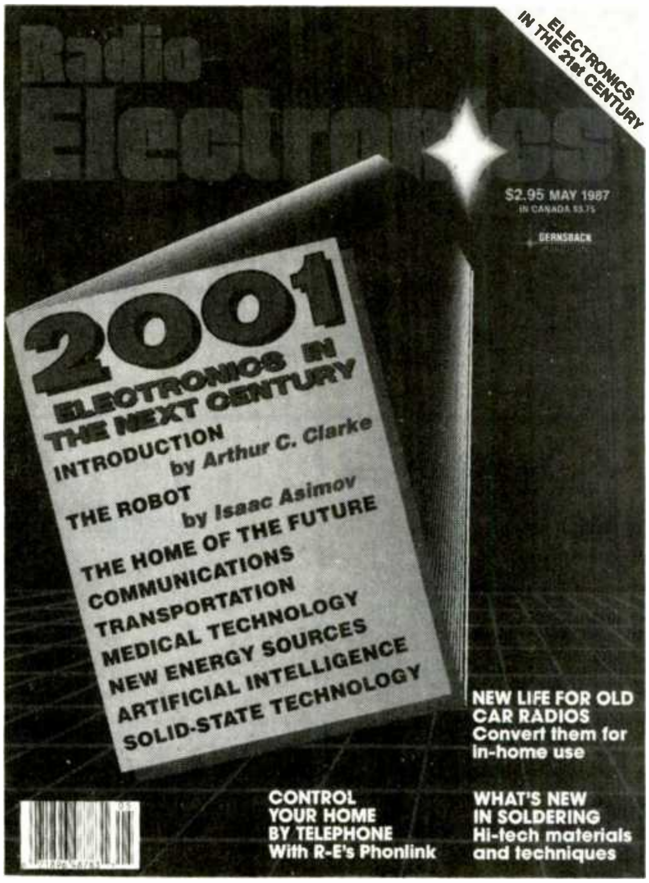

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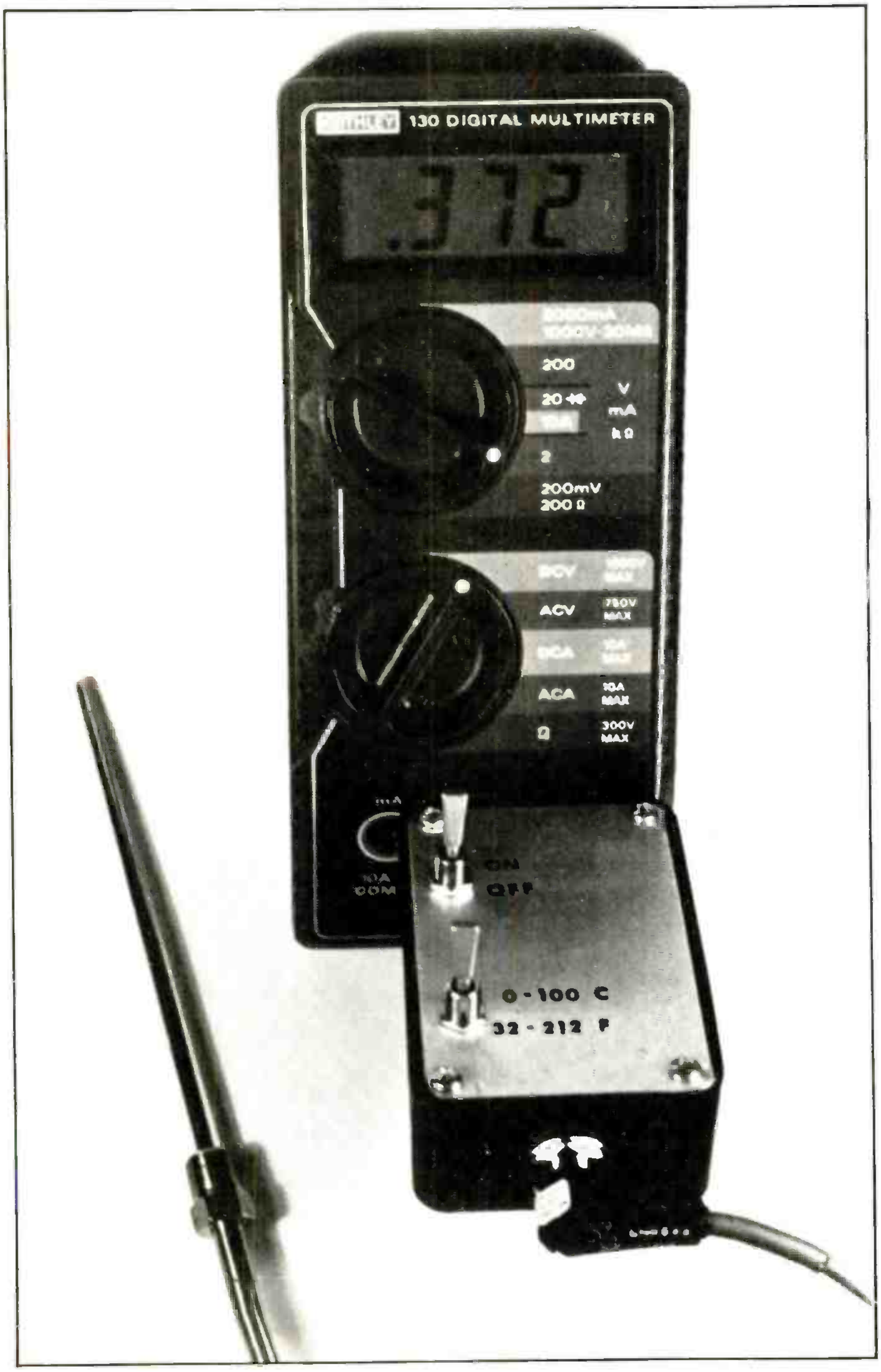
Temperature Measuring add-on for your DMM

If you own a digital voltmeter, you already have one half of a precision digital thermometer. Here's how to build the other half.

HARRY L. TRIETLY



A PRECISE DIGITAL THERMOMETER CAN have a wide variety of uses around the home and shop. Whether you need to check the operation of your heating system or your refrigerator, to test a circuit for hot spots, or to measure the outdoor temperature, a digital thermometer can help make it easy.

The only problem is that a thermometer that can read to one tenth of one degree can cost well in excess of one hundred dollars. But if you own a DVM, you already have half of such a thermometer. All you have to do is to add a precision thermistor and the single-IC interface circuit that we'll describe here.

The DVM-to-temperature adapter can be built for one of two temperature ranges. The first range is from 0 to 100 degrees Celsius (or 32 to 212 degrees Fahrenheit). Alternately, the adapter may be designed for a range of −30 to 50°C (−22 to 122°F). In either case, the output provided is ten millivolts per degree. A DVM with a sensitivity of one millivolt will yield a resolution of 0.1 degree. Accuracy will be 0.4°C or better, exclusive of the DVM.

The thermistor

In our thermometer, the temperature sensor is a network made up of two precision thermistors and two resistors. Using a single thermistor would not be desirable because its resistance-versus-temperature characteristic is highly nonlinear, as we can see from Fig. 1. If a thermistor is used in a Wheatstone bridge, however, its output characteristic is reasonably linear over a limited temperature range. (See Fig. 2) For example, linearity within ±1°C is possible over a 0 to 50°C range. The linear range will be approximately centered at the temperature where the thermistor's resistance equals the series fixed resistor.

Figure 3 shows a way to improve the linearity even more by adding a second thermistor and resistor. Not only does that improve the linearity, but it also extends the linear range. From 0 to 100°C, for instance, linearity will be within ±0.22°C. Thermistor pairs are specifi-

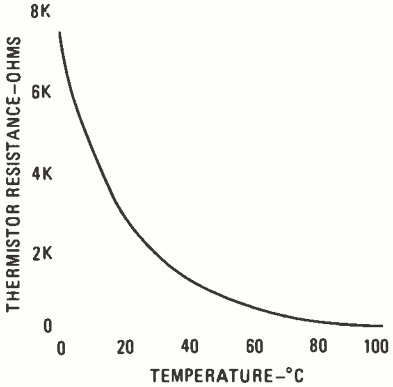


FIG. 1—A SINGLE THERMISTOR has a highly nonlinear resistance-vs.-temperature characteristic.

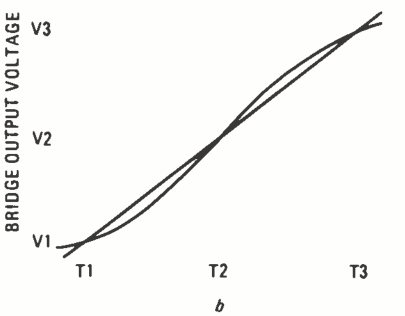


FIG. 2—WHEN USED IN A WHEATSTONE BRIDGE, a thermistor can provide a nearly linear output over a limited temperature range.

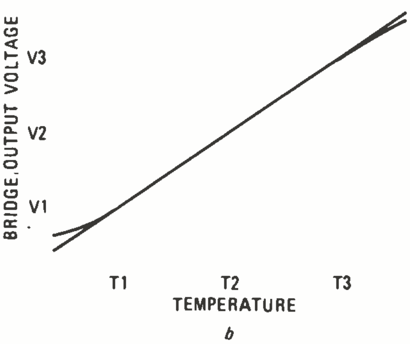


FIG. 3—ADDING A SECOND THERMISTOR greatly improves the linearity and extends the linear range.

cally chosen for that use and packaged as a single, three-lead component. The prototype was built using a composite manufactured for the Yellow Springs Instrument Company (Box 465, Yellow Springs, Ohio 45387) and sold under the trade name *Thermilinear*. A distributor for the composite is mentioned in the Parts List, but you can contact YSI for a distributor near you. Other manufacturers also offer similar devices.

Calculating the values for the fixed resistors is not easy, but the manufacturers have precalculated optimum network values for several temperature ranges and can calculate others using specially-developed computer programs. (For more information on thermistors and thermistor networks, see the January through March 1985 issues of **Radio-Electronics**.)

The adapter circuit

As shown in Fig. 4, the DVM-to-temperature adapter is built around a single IC, National's LM10. That micropower IC contains a stable 0.2-volt reference, a reference amplifier and a general-purpose operational amplifier. The remainder of the adapter's circuit requires only eight fixed resistors, two switches, and four trimmer potentiometers. It can be simplified farther if Fahrenheit/Celsius switching is not needed.

The circuit of Fig. 4 is designed for a linear temperature range of 0 to 100°C (32 to 212°F). Minor changes to the circuit and resistor values will let you measure from −30 to 50°C (−22 to 122°F) instead. That circuit is shown in Fig. 5. Note that many of the part numbers are the same as in Fig. 4. Keep that in mind when selecting parts for the thermometer and when studying the Parts List.

The 0.2-volt reference and reference amplifier provide a stable, fixed excitation voltage to the Wheatstone bridge. The voltage is determined by a feedback network consisting of R1 through R6. Switch S2-a configures the feedback to increase the voltage from 0.6 volt on the Celsius range to 1.08 volts on the Fahrenheit range, compensating for the fact that one degree Fahrenheit produces a smaller resistance change than does one degree Celsius.

Resistors R1 through R6 also form the fixed leg of the Wheatstone bridge, nulling the bridge output at zero degrees. Since 0°C is different from 0°F, S2-b is used to select the appropriate offset. The measurement leg of the bridge is formed by the R_T1 and R_T2 (the *Thermilinear* composite) along with fixed resistors R7 and R8. Those two fixed resistors must have a tolerance of 0.1% or better to achieve the full rated accuracy and linearity of the network. A source for the resistors is given in the Parts List, but you can create your own from series-parallel resistor combinations using a 0.1% or better ohmmeter.

The LM10's operational amplifier, along with R9 through R12, forms a differential amplifier that boosts the bridge output to 10 millivolts per degree. Since a single supply is used, and since the output must be able to swing both positive and negative, the output is referenced to the bridge supply voltage rather than to supply common.

Building the converter

Due to the simplicity of the circuit and the fact that the layout is not at all critical, it is not necessary to use a custom-designed circuit board. As you can see in Fig. 6, the converter was built using a prototyping board, which is housed in a small plastic experimenter's box. Connections to the *Thermilinear* composite are made via J1, a 1/4-inch, 3-connector phone jack. Other jacks may be used, of course. The phone jack was chosen because it mated with the probe used (YSI 700 series probe). An enclosed-type jack is used, and is glued to the circuit board. That allows the jack to be used to mount the board to the case via the jack's mounting hole. Before gluing the jack to the board, resistor R7 is connected between the tip and ring terminals and two connecting wires are soldered to the ring and barrel.The board is sized so that when installed, just enough space is left be-

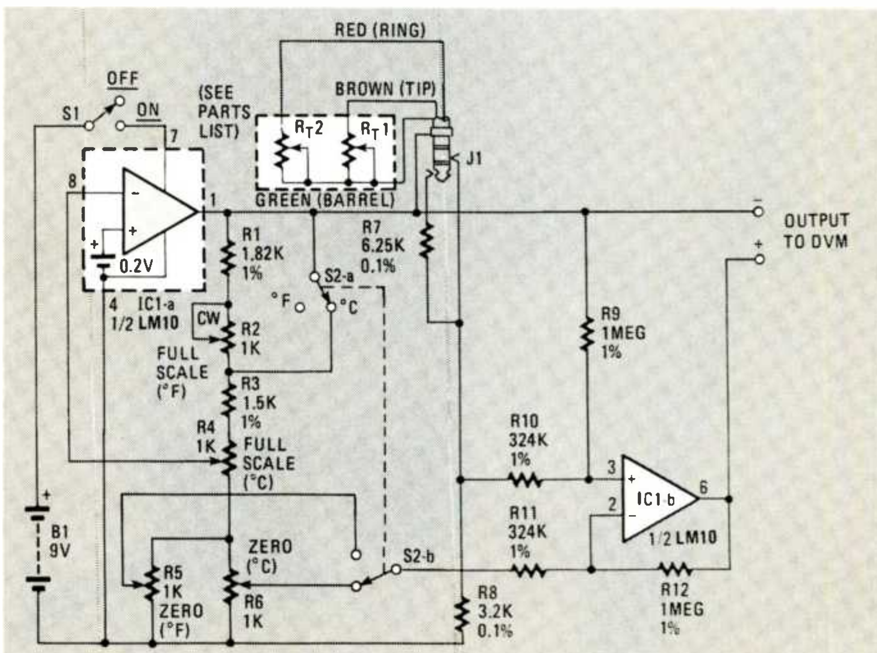


FIG. 4—THE ADAPTER CIRCUIT for a range from 0 –100 C. It uses only one IC, which supplies both the reference voltage and the bridge amplifier.

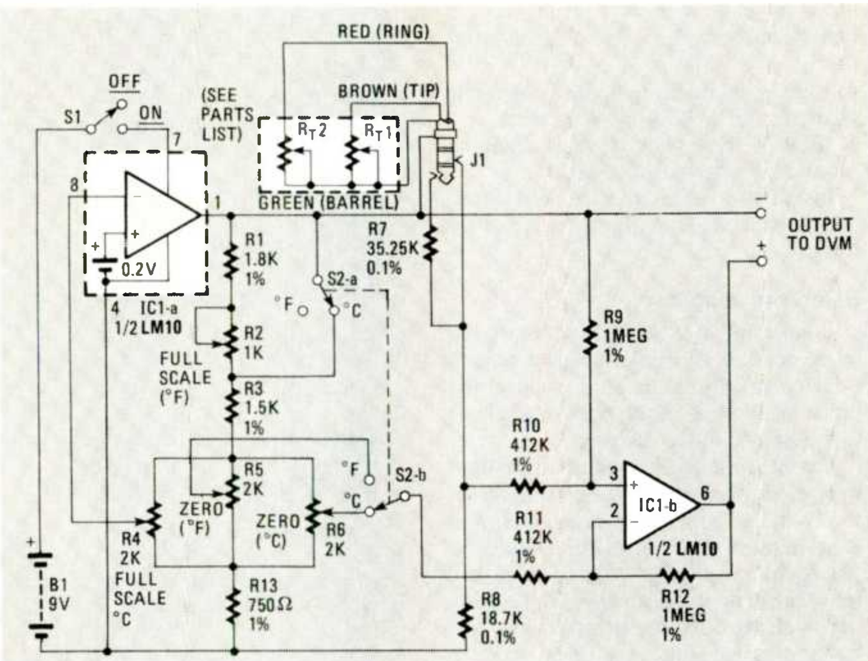


FIG. 5—THIS SLIGHTLY MODIFIED CIRCUIT measures from −30–+50 C.

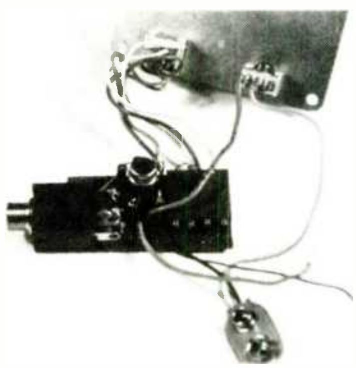


FIG. 6—THE COMPLETED BOARD before installation. Note that the IC is in a TO-5 package, not a DIP.

tween its edge and the side of the case to contain a 9-volt transistor radio battery.

Figure 7 shows the component layout for the 0 to 100°C circuit. Construction details are not shown for the −30 to 50°C range, but only minor changes from the 0 to 100°C layout are required. Be sure to cut out a portion of the breadboard corresponding to the layout shown.

Begin assembly by cutting lead 5 from the LM10 IC. That lead is not used, and the corresponding pad on the circuit board is used as a tie point. Insert and solder the IC, resistors, trimmer potentiometers, and the seven wires for connection to the switches, battery and output. Turn the board over and install the eleven jumpers (shown as dashed lines in Fig. 7) and the two additional switch wires. Jumpers between adjacent pads may simply be solder bridges. Complete the board assembly by installing the prewired phone jack.

Drill a hole at one end of the case for the phone jack, located so as to hold the board in the correct position. At the other end drill two holes 3/4 inch apart and install the banana plugs. Standard banana plugs may be held in place using 1/4-28 nuts in place of the screw-on plastic insulators. Drill holes and install the two switches in the box's cover. Wire the board, switches, battery, and banana plugs. For most DVM's the left banana plug should be positive: Check your meter and wire accordingly. Remember also to connect the positive battery terminal to S1. At this point, your board should look something like that shown in Fig. 6. Do not install the board in the case until after calibration.

Calibration

The Thermilinear composite is a precision device, specified at ±0.15°C accuracy or better from −30 to 100°C. Thus, calibration requires no temperature baths; only a precision resistor to simulate the thermistors. Use a precision (0.1% or better) decade box or create 0.1% calibration resistances using series-parallel resistors and a 0.1% or better ohmmeter.

Connect the calibration resistor in place of thermistor T2; No connection is necessary in place of T1. If you have built the 0 to 100°C version proceed as follows:

1. Set the C/F switch to C. Provide 20,519 ohms input and adjust R6 for 0 millivolts output.

2. Change the input to 1578.7 ohms and adjust R4 for a 1000 millivolt output.

3. Set the C/F switch to F. Provide a 77,387 ohm input and adjust R5 for a 0 millivolts output.

4. Change the input to 2094.9 ohms and adjust R2 for 1900 millivolts output.

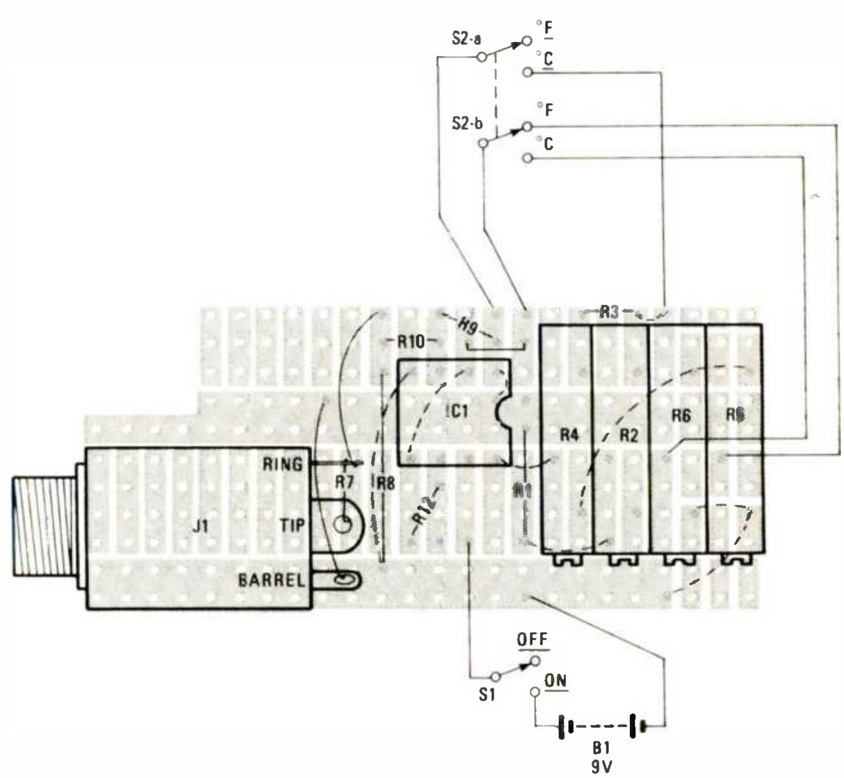


FIG. 7—CIRCUIT-BOARD ASSEMBLY using a "universal circuit board." Most of the fixed resistors must be "hairpinned" and stood on end to fit in the space allowed. Cut pin 5 from IC1—it's not needed, and a jumper is installed in its position. Note that top-side and bottom-side jumpers are shown. Those on the bottom are shown dasned. Solder R7 directly between the ring and tip of J1 before gluing the jack to the board.

FIG. 8—THE ASSEMBLED CONVERTER ready to be plugged into a DVM.

5. Repeat the previous steps, making minor readjustments if necessary.

For the −30 to 50°C version:

1. Set the C/F switch to C. Provide a 34,651 ohms input in place of T2 and adjust R6 for 0 millivolts output.
2. Change the input to 8536.2 ohms and adjust R4 for 500 millivolts output.
3. Set the C/F switch to F. Provide 63,115 ohms input and adjust R5 for 0 millivolts output.
4. Change the input to 8536.2 ohms and adjust R2 for 1220 millivolts output.
5. Repeat the previous steps, making minor readjustments if necesary.

Install the board, battery, and cover, and the adapter, see Fig. 8, is ready for use.

Using the adapter

Connecting the thermistor composite to the adatpor is simple. Using a ¼-inch three-conductor phone plug, connect the green lead to the barrel, brown (or clear) to the tip and red to the ring.

For measuring air temperature the thermistor composite should be exposed directly to the air. For measuring liquid temperatures the thermistor should be placed inside a metal, glass, or plastic tube whose tip has been closed by soldering, welding, melting or epoxying. For fastest response time, the space betweer the thermistor and the tube should be filled with epoxy. For measuring surface temperatures the thermistor should be thermally bonded to the surface with heat-sink compound. If you prefer, ready made probe assemblies are available. Contact YSI for more information.

To use the adapter, set your DVM to a DC voltage range having a sensitivity of one millivolt or better. Plug the thermistor composite or probe into the adapter and the adapter into the meter, turn the adapter on and read temperature. The meter will read ten millivolts per degree so that, for example, 1.000 volts (1000 millivolts) indicates 100.0 degrees. Readings may be converted from Celsius to Fahrenheit simply by throwing the C/F switch.

Within its range, the units accuracy will be excellent. The worst-case error will be the sum of the thermistor's specified accuracy (±0.15°C, or 0.27°F), your DVM's accuracy and the Thermilinear network's nonlinearity. That error may be corrected for using the graphs in Figs. 9 and 10. For example, on the 0 to 100°C range, the reading will be 0.12°C too high at 33°C and 0.20°C too low at 60°C. **R-E**

PARTS LIST—0-100°C VERSION

Resistors
R1—1820 ohms, 1%
R2, R4, R5, R6—1000-ohm multiturn trimmer potentiometer
R3—1500 ohms, 1%
R7—6250 ohms, 0.1%
R8—3200 ohms, 0.1%
R9,R12—1 megohm, 1%
R10,R11—324,000 ohms, 1%
R_T1, R_T2—Thermilinear composite

Semiconductors
IC1—LM10 op amp/voltage regulator IC (National)

Other components
S1—SPST miniature toggle switch
S2—DPDT miniature toggle switch

Miscellaneous: Prototyping board, plastic case, ¼-inch three-conductor phone jack (enclosed type), banana plugs, 9-volt battery and connector, etc.

PARTS LIST—−30–+50° VERSION

As above, except:
R4, R5, R6—2000 ohms multiturn trimmer potentiometer
R10, R11—412,000 ohms, 1%
R13—750 ohms, 1%

R_T1, R_T2, R7, and R8 are available as a complete set of components as YSI part no. 44201 (0-100°C) or 44203 (−30–+50°C). The price is $24 from Newark Electronics, Route 22 East, Springfield, NJ 07081. Contact YSI Industrial Sales, Yellow Springs, OH 45387 for the name of the distributor nearest you.

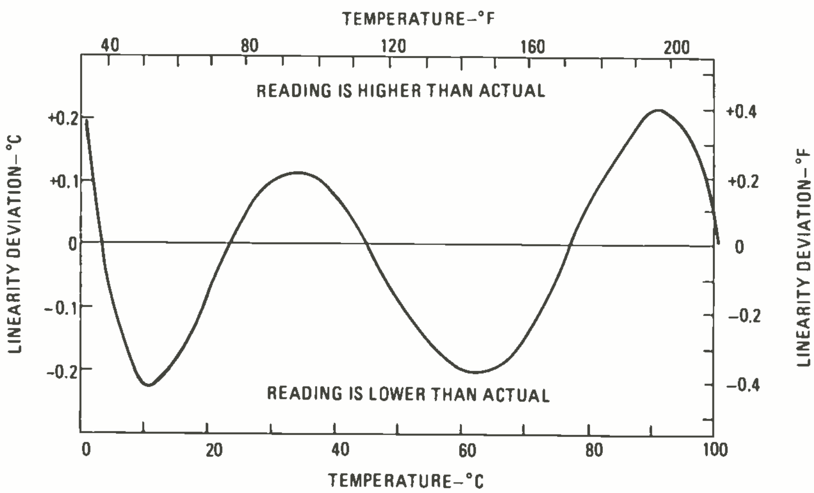


FIG. 9—TO CORRECT FOR NONLINEARITY ERRORS on the 0-100°C range, use this curve.

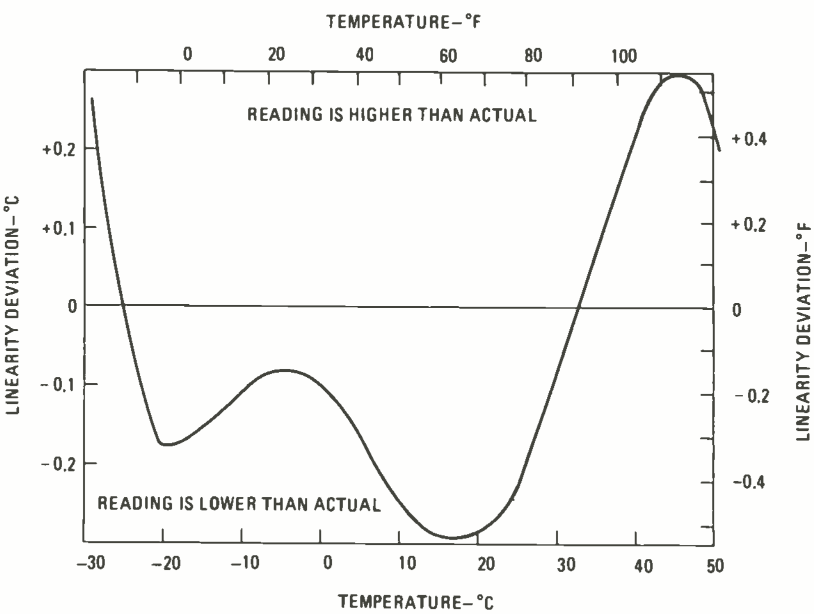
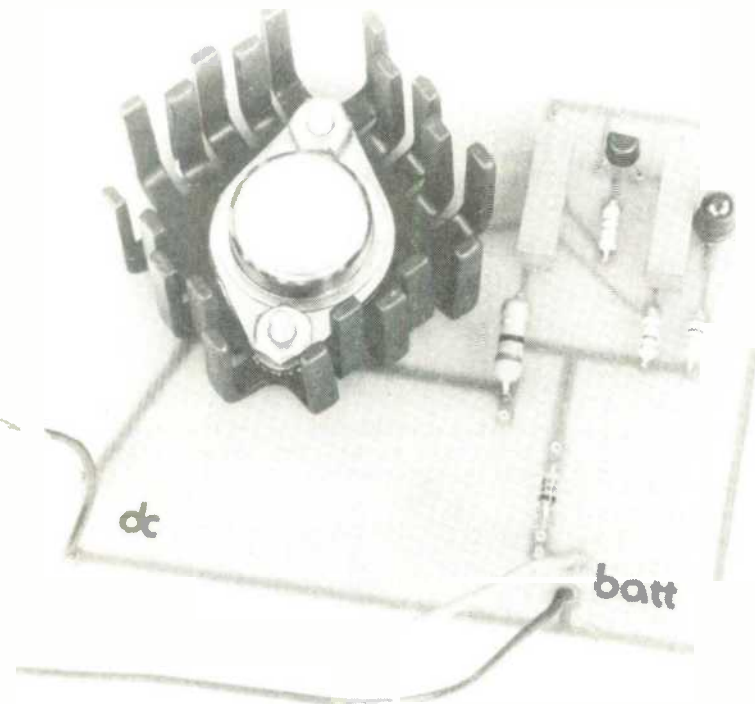


FIG. 10—TO CORRECT FOR NONLINEARITY ERRORS on the −30–+50 C range, use this curve.



Universal Battery Charger

Don't let your battery-powered portables run out of energy unexpectedly! Keep your batteries fully charged with this inexpensive circuit.

MICHAEL R. WRIGHT

ONE COROLLARY TO MURPHY'S LAW states that things always go wrong at the worst possible moment. One example familiar to electronics enthusiasts is the way that batteries tend to go dead just when you need them most. In addition, if you use many portable devices—a *Walkman*, a "boom-box," a portable TV, a portable computer, flashlights, and toys—the cost of batteries can become excessive.

One way to cut costs is to use rechargeable batteries. And if your portable battery-eater has a DC INPUT jack, you've got an easy way to save some cash and to go longer between recharges. All you have to do is wire up a cable that connects a high-current-capacity battery-pack of the proper voltage to your portable.

The problem is that the price of a commercial charger may cause you to think twice about converting from conventional non-rechargable cells. However, with the circuit presented here, there's no longer an excuse. Not counting a case, the total cost of the few easy-to-obtain components in our circuit shouldn't exceed $10. And that's for all new parts; by using spare parts you could reduce your cost to nothing!

The circuit can easily recharge batteries with a wide variety of voltages and current capacities. The circuit was specifically designed to recharge gel-cells, but it can also be used to recharge Ni-Cd's and any other type of battery that needs a constant-current source, a constant-voltage source, or both. The values of a few resistors need to be altered to accommodate batteries of various voltages and currents. The simple design equations used for resistor selection are presented below, but first let's talk about gel-cells.

The low-down on gel-cells

Before we get started, it's worth pointing out that the term "battery" really refers to any collection of two or more single "cells," although the term is loosely applied to single-cell power sources like AA cells. The gel-cell battery is a relative newcomer to the world of rechargable batteries; its name is really a shortened from of "gelled-electrolyte battery cell."

Basically, the gel-cell is very similar to a modern automotive battery. The gel-cell provides high power density in a sealed, multi-cell, maintenance-free, lead-acid battery. Gel-cells are not manufactured in small cases like those that enclose the familiar AA, C, and D cells. However, they *are* manufactured in larger cases that range in size from a cigarette-pack to an automobile battery, and even larger. Gel-cells are made by (among others) Panasonic (Battery Sales Division, Division of Matsushita, P. O. Box 1511, Secaucus, NJ 07094), Globe (P. O. Box 591, Milwaukee, WI 53201), and Saft (P. O. Box 1886, 711 Industrial Blvd., Valdosta, GA 31603-1886).

Common gel-cell batteries come with voltage ratings that range from 2 to 24, and in current capacities ranging from 1.2 to 120 AH (*A*mp-*H*ours). The AH rating refers to the amount of current that can be delivered over a period of time; 20 hours is usually the specified period of time. For example, a battery might be rated at 2 volts and 30 AH. That means that the battery should be able to deliver a current of 1.5 amps (30/20) continuously for a period of twenty hours.

A properly treated battery should last for years, but an improperly treated one may last only a few months, or even weeks. For example, the author's first gel-cell battery lasted only about six weeks, because he was ignorant of how to take care of it. After uncovering and applying the information related here, his second one is already more than a year old and still going strong.

The most common means by which a gel-cell battery is abused is "deep-cycling;" that term refers to the practice of discharging a battery deeply and then over-charging it. That practice is sometimes appropriate for Ni-Cd's, but it is definitely inappropriate for gel-cells. Our charger can't repair a damaged or abused gel-cell battery; it's up to you to treat your batteries with care.

The number of cells in a gel-cell battery is equal to the battery's nominal voltage divided by two. A 12-volt battery therefore has six (12/2) cells. Each cell has a 2.3-volt output when it is fully charged, so a 6-cell battery, nominally rated at 12 volts, actually has a fully-charged output of 13.8 volts.

You can tell when a gel-cell battery is nearly discharged by the fact that, under a no-load or low-load condition, it will have an output voltage that is near its full rated output. However, when the battery is placed under a moderate to heavy load, voltage drops by about 4.6 volts.

The reason for the two-cell drop is that a discharged cell actually reverses polarity and acts as a load that "cancels" the voltage of a good cell. So you might measure only about 9.2 volts (13.8 − 4.6 = 9.2) across a 12-volt battery that needs to be recharged. And speaking of charging, let's find out how to do it now.

Charging methods

Gel-cell batteries from different manufacturers are made in different ways, and they have different charging requirements. Many batteries can be charged using the circuitry described here, but you should check with the manufacturer of your battery to be sure.

A common and reliable method of charging is as follows. First, a regulated, constant current that is equal to 10% of rated output is applied to the battery. For example, a 12-volt 1-AH battery would start off with a charging current of 100 mA. Voltage must be monitored; when it reaches 90% of rated output, the circuit removes the constant-current source and applies a regulated voltage to complete charging. The switchover is necessary to prevent over-charging in case a battery is left connected to the charger for a long period of time. The battery can float-charge in that way indefinitely.

You may be able to use a charging current different than 10%—for example, for "fast-charging." However, if you use a different current, follow the manufacturer's recommendations carefully.

To determine the voltage the charger will have to supply, you'll have to multiply the number of cells in your battery by 2.3 and then add 5, to allow for circuit losses. To charge our example 12-volt battery,

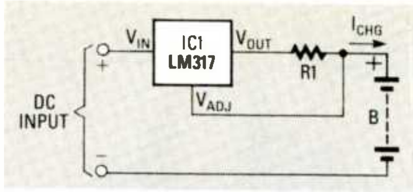


FIG. 1—A CONSTANT-CURRENT CHARGER can be built from an LM317. The value of R1 is what determines the charging current. See the text for information on how to calculate its value.

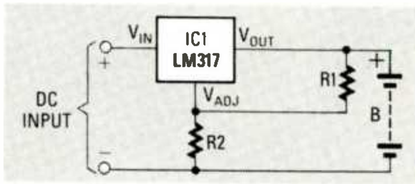


FIG. 2—A CONVENTIONAL VOLTAGE regulator is easy to build with an LM317; the value of R2 sets the output voltage.

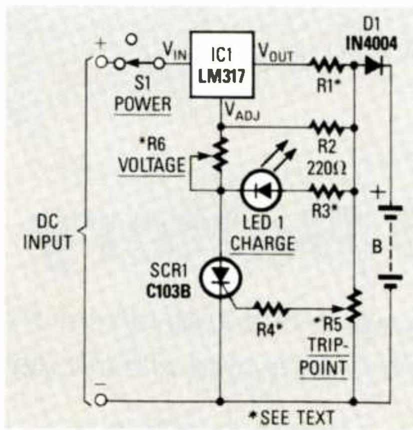


FIG. 3—THE COMPLETE CHARGER is a hybrid of the previous circuits. When the SCR is off, the circuit functions as a constant-current source; when the SCR is on, the circuit functions as a voltage regulator.

we'll actually need an unregulated DC supply of about 19 volts.

Circuitry

The constant-current charger is right out of the manufacturer's data book. As shown in Fig. 1, the heart of the charger is an LM317 adjustable regulator. An LM317K can supply as much as 1.5 amps of current if it has proper heatsinking; it can also handle as much as 37 volts. If your battery requires a higher charging voltage, you can substitute an LM317HV, which can handle as much as 57 volts. To increase current, you could use an LM338, which can provide five amps of current at a maximum of 32 volts. Calculate the value of R1 from the charge current (I_{CC}) you need, and from the 1.25-volt bias required by the LM317:

$$R1 = 1.25/I_{CC}$$

For a 1-AH battery, $I_{CC} = 0.1$ A, so R1 = (1.25/0.1) = 12.5 ohms. R1's wattage is determined in the usual manner: 0.1 A × 1.25 V = 0.125 W. Just to be safe, use a ½-watt flame-proof resistor.

That takes care of current, but what about voltage? Take a look at Fig. 2. There an LM317 is configured as a conventional constant-voltage regulator. In normal applications, the manufacturer recommends that R1 have a value of 240 ohms. The value of R2 is what determines the output voltage, and its value may be arrived at by a fairly complex equation. It's usually simpler to wire up the circuit with a 5K or a 10K potentiometer, set the output voltage, and then substitute the closest standard fixed resistor for the potentiometer.

We've got a current regulator and a voltage regulator now. But how do we put them together? See Fig. 3.

The complete charger

Let's discuss the overall operation of the circuit and then show how to calculate resistor values. When power is applied to the circuit, SCR1 is off, so there is no bias-current path to ground; thus, the LM317 acts as a current regulator. The LM317 is connected to the battery through steering diode D1, limiting resistor R1, and bias resistor R2. That portion of the charger is similar to the circuit shown in Fig. 1 above. The steering diode was added to prevent the battery from discharging through the LED and the SCR when power is removed from the circuit.

As the battery charges, the voltage across TRIP-POINT potentiometer R5 rises and at some point turns on the SCR. At that point, current from the regulator can flow to ground, so the regulator now functions in the voltage mode. When the SCR turns on, it also provides LED1 with a path to ground (through R3). So, when LED1 is on, the circuit is in the voltage-regulating mode; when LED1 is off, the circuit is in the current-regulating mode.

Calculating resistor values

Now let's find out how to calculate the resistor values. Assume that we're still talking about a 12-volt, 1-AH battery. Let's start with the VOLTAGE adjustment potentiometer, R6. First we have to calculate a multiplication factor, F; that can be found from:

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.
R1, R3, R4, R6—see text
R2—220 ohms
R5, R6—ten-turn trimmer potentiometer, see text
Semiconductors
IC1—LM317 variable-voltage regulator
D1—1N4004
LED1—standard LED
SCR1—C103B, 800 mA, 200-volt SCR
Miscellaneous
SPST toggle switch, PC board, input and output connectors

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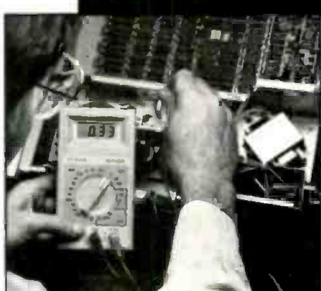

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5-057

TABLE 1—EVERREADY Ni-Cd CHARGE CURRENT

Number	Size	Charge Current	Charge Voltage
CF15	AA	50 mA	1.50–1.60
CH15	AA	50 mA	1.35–1.45
CH35	C	120 mA	1.35–1.45
CH50	D	120 MA	1.35–1.45

$$F = (V_{CC}/1.25) + 1$$

In that equation V_{CC} is the battery's full-charge output voltage; in our case, $V_{CC} = 13.8$, so $F = (13.8/1.25) + 1 = 12.04$. Then we calculate the value of R6 as:

$$R6 = F(R1 + R2)$$

We already saw that R1 has a value of 12.5 ohms; R2 has a value of 220 ohms, so $R6 = 12 \times (220 + 12.5) = 2800$ ohms. That value is approximately what is required to obtain the end-of-charge voltage we need. The value is an approximation because it does not take into account the voltage drop across the SCR. So we simply round up to the next highest value, and use a 5K potentiometer for R6. That will allow you to adjust the circuit for use with batteries having different voltages.

The manufacturer recommends that R2 have a value of about 240 ohms. The series combination of R1 and R2 is within 5% of 240 ohms, and that's close enough. You may have to adjust the value of R2 to accommodate a different charge current, voltage, or both, or if you use the high-current LM338. See the 1982 *Voltage Regulator Handbook* by National Semiconductor (2900 Semiconductor Drive, P. O. Box 58090, Santa Clara, CA 95052-8090) for more information.

Next we need to determine the value of TRIP-POINT potentiometer R5, which sets the voltage at which the SCR turns on. We have found empirically that, if the end-of-charge voltage is less than 20 volts, a 5K unit will work. For voltages greater than 20 volts, a 10K unit will work.

The value of the LED's current-limiting resistor, R3, is easy to calculate:

$$R3 = (V_{CC} - 2.2)/20 \text{ mA}$$

$$R3 = (13.8 - 2.2)/0.02 = 580\Omega$$

You may want to substitute a 1000-ohm ½-watt resistor for R3. Doing that will prevent damage to the LED when the charger is used with batteries having voltages greater than 12.

The last value we need to calculate is that of R4, which limits the current that can be applied to the gate of SCR1. That current could blow the SCR if the TRIP-POINT potentiometer were turned too far in the direction of the output of the regulator. The value of R4 may be determined thus:

$$R4 = V_{CC}/50 \text{ mA}$$

So, in our case,

$$R4 = 13.8/0.05 = 276\Omega$$

Rounding up to provide extra current limiting, the closest standard value is 300 ohms, which should work fine.

Regarding the SCR, it must be able to handle the bias current of the LM317K when the latter is in the voltage mode, and it must be able to withstand the full, no-load voltage supplied by your DC source—19 volts in our example. The SCR specified is rated to handle 200 volts at 800 mA; it should be able to handle any battery you're likely to come across.

Construction

Layout and assembly are quite simple; a foil-pattern for a printed-circuit board is shown in "PC Service." A stuffing guide is shown in Fig. 4. Stuff the board, solder the components, and then check your work to make sure that the semiconductors are all oriented correctly.

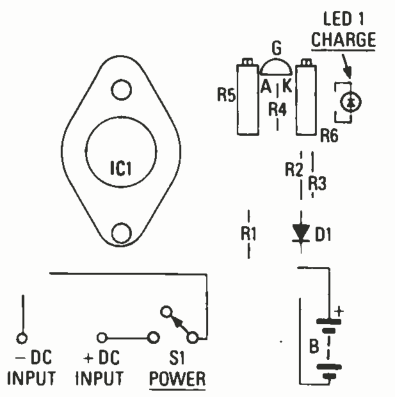


FIG. 4—PARTS-PLACEMENT DIAGRAM for the complete voltage/current charging circuit shown in Fig. 3.

Before applying power, set both trimmer potentiometers (R5 and R6) to the middle of their ranges; and *don't* connect the DC source or a battery to the charger yet. You must calibrate the charger first. We'll continue working with a 12-volt, 1-AH battery; substitute the appropriate values for your battery where necessary.

1. Connect an ohmmeter across the VOLTAGE adjustment potentiometer (R6). Adjust R6 so that the ohmmeter indicates the calculated set-point value—2.8K, in the example. Remove the ohmmeter from the circuit before proceeding.

2. Apply power to the circuit and check for smoke and other signs of catastrophe. Fix any mistakes.

3. Connect a 4.7K resistor to the circuit where the battery would normally.

4. Apply power to the circuit and measure the voltage across the 4.7K resistor. That voltage should be about 13.8, or your calculated output voltage. If the measured voltage is much different from what you expect, measure the voltage across the SCR. If you don't measure about 0.7 volts, the SCR has not turned on, so adjust TRIP-POINT potentiometer (R5) until the LED turns on. If the LED won't turn on, the SCR may be bad.

5. Connect a voltmeter across the output terminals and adjust the VOLTAGE control (R6) so that the meter indicates your calculated V_{CC}—19 volts, in our case.

6. De-energize the circuit and connect an ohmmeter between the wiper of the TRIP-POINT potentiometer (R5) and ground. Adjust R5 so that the meter reads zero ohms. That will disable the current-to-voltage shift. Remove the ohmmeter and the 4.7K resistor.

7. Connect a partially-discharged gel-cell battery to the output terminals of the charger. *Be careful to observe proper polarity!* The LED should not light; if it does, steering diode D1 is in the circuit backward.

8. Connect a voltmeter across the battery, apply power to the circuit, and measure the voltage across the battery. If the battery is not discharged enough, V_{CC} may be reached before you have a chance to adjust R5. If your meter indicates V_{CC} now, you'll have to discharge your battery further and try again. What you want to do is adjust R5 so that the SCR trips just after V_{CC} is reached.

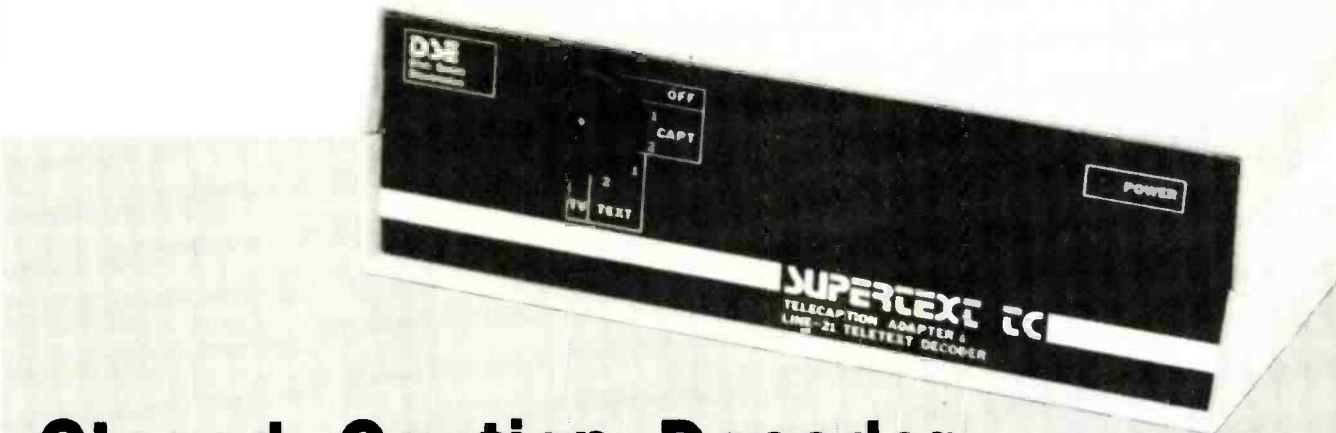
9. Partially discharge the battery and reset R5 several times until you're satisfied with the accuracy of the trip-point setting.

Charger use

When charging a battery, you'll want to take an occasional look at LED1. After it turns on, interrupt power for about three seconds. That allows the SCR to unlatch. Re-apply power, and, if the LED re-illuminates quickly, the battery is fully charged. If not, let the battery charge longer and then repeat the test.

You can also use this circuit to recharge lead-acid and Ni-Cd batteries. You'll have to re-calculate resistor values to provide the appropriate charging current, which can be obtained from manufacturers' data books. We show the required charge current for several common *Eveready* Ni-Cd cells in Table 1 as a point of reference.

When charging a (non gel-cell) lead-acid or Ni-Cd battery, power should be removed when the LED lights up, or overcharging may occur, and the battery may be damaged.



Closed-Caption Decoder

J. DANIEL GIFFORD

Closed-captioning—what's it all about? Find out here, and build a high-performance, low-cost closed-caption decoder, too.

MORE AND MORE GOOD PROGRAMS ARE appearing on TV lately, especially on the cable channels. And more and more good films are coming out on videotape. But until recently not everyone could fully enjoy those programs—especially people with a hearing disability. Since 1979, however, many TV shows have been broadcast and many videotapes have been released that use *closed captioning*—a method whereby hearing-impaired persons can read dialog and narration on the screen in real time—while the actor or announcer is speaking!

All it takes is our inexpensive adapter to allow a hearing-impaired person to enjoy all the benefits of modern programming. Because most of the circuitry comes on a pre-built module, the decoder can be built easily in an evening or two for under $150.

To use the decoder, feed the audio and video outputs of a VCR, a component-TV tuner, or a satellite receiver to the adapter, and connect its outputs to the corresponding inputs of your receiving device. If your receiver has no audio and video inputs, you can add an RF modulator to provide input directly to your receiver's antenna terminals.

How it works

Closed captioning is the term for the written subtitles that are encoded in a television program or on a videotape. An often-asked question is why the captions are "closed," or normally invisible, instead of "open" and visible all the time. The answer is that, although captions are a boon to the hearing-impaired viewer, they can annoy and distract other viewers.

Normally the subtitles are not visible on the screen, but when a video signal carrying closed-caption data is passed through a decoder, that data can be extracted from the signal and converted into visible captions that can be placed just about anywhere on the screen. The captions usually appear at the bottom of the picture and provide, in a readable (and slightly edited) form, both dialogue and narration.

To avoid blocking on-screen action, or to better identify who is speaking when more than one person is visible, the captions can be placed on the screen strategically. Significant sounds that are not apparent from the on-screen action (such as off-camera screams, door slams, and gunshots) can also be captioned, and usually are placed in brackets: [gunshot], [shouts], etc.

There are numerous closed-captioned programs on TV these days. For example, almost half of the network movies, most of the regular prime-time series, and many news and educational programs are currently closed-captioned. The three networks (most notably ABC) and the PBS system carry more than a hundred hours of captioned programming a week. Many pay-TV services also carry captioned programs (some 30 hours a week), including HBO/Cinemax and Showtime/The Movie Channel.

In addition to broadcast programming, hundreds of popular video-taped movies have also been captioned. The total number of titles that are available at press time should exceed 600; approximately 25 titles are added every month. Captioned movies are identified by a closed-caption symbol on the package.

Closed-captioning provides more than just captions. There are nationwide full-page text services that summarize news, sports scores, special information for the hearing impaired, and even provide a complete list of currently broadcast closed-captioned programs.

As you might suspect, all that information cannot be packed into a single captioning channel. In fact, there are two captioning channels and two text channels, all of which operate simultaneously. Caption channel 1 (C1) is used for regular caption information. Caption channel 2 (C2) is largely unused at the present, but will most likely find use in "alternate-text" captioning. For example, second-language captioning, simplified text for children, and verbatim captions (which may move too fast for some viewers to read) are all possible uses for C2.

Both Text channel 1 (T1) and Text channel 2 (T2) are in wide use, however. On ABC, T2 is used more or less continuously to transmit the *P*rogram *L*isting *U*pdate *S*ervice (PLUS), which is a rolling list of all current broadcast and pay-TV programs that are captioned, including movies.

T1 is used simultaneously to carry other text services such as The News Summary, which is broadcast Monday through Friday during the program "Nightline;" Weekend Scoreboard (a list of current sports scores and rankings), broadcast Saturdays between 8 and 11 PM and Sundays between 7 and 11 PM (Eastern times); and the *H*earing *I*mpaired *N*ews

INSTANT CAPTIONING can now be added to live programming.

Text Service (HINTS), a list of news and information of concern to the deaf and hearing impaired, broadcast Mondays and Thursdays between 8 and 9 PM. PLUS and the other services also can be found on some PBS stations.

Both the existence and the widespread use of the closed-caption system in the US are the result of an almost single-handed effort by the National Captioning Institute (5203 Leesburg Pike, Falls Church, VA 22041), a non-profit corporation whose sole purpose is to develop and further closed captioning. From its beginnings in 1979, NCI has moved closed captioning from the status of a novelty to that of a viable communications medium for a sizable portion of the population. NCI is responsible for all phases of captioning, from fundraising, to research and development of new equipment and techniques, to the actual production of captions for programs.

Making captions

Program captions are produced by a rather lengthy process in which the program to be captioned is viewed, trial captions are added, the result is reviewed and edited, and so on until a finished set of captions that accurately follows both dialogue and action has been produced. It takes about 30 hours of work to produce captions for a one-hour program, at a cost of about $2,500.

For broadcast programs, the caption data is encoded on a floppy disk and sent to the broadcast center, where it is added to the video signal for transmission with the program. The caption data is added to videotapes during duplication.

Although most captioning is done in advance for pre-recorded programs, a recent development (by NCI) allows instant captioning. In that type of captioning, which is used mostly for news programs and live speeches, a caption programmer listens to the program and enters the words spoken into a computer, using a keyboard similar to that of a court reporter's. A sophisticated computer program identifies the word groups, and converts them to caption form. The captions thus produced roll upwards on the bottom three lines of the screen at a rate more or less equal to the speed with which they are spoken. Although the captions lag slightly behind the spoken words (due to the time required for entry and translation), they appear very quickly and are, for all practical purposes, instantaneous.

The line-21 system

The text channels and closed captions are variations of a teletext system known as the Line-21 System, so called because data is transmitted on video line 21. A number of experimental teletext systems using the Line-21 format have come and gone in the US, most notably the original INFOTEXT service in Wisconsin. However, most teletext systems use either the WST (*World System Teletext*) or NABTS (*North American Broadcast Teletext System*) formats, because they offer better graphics and more flexibility than the Line-21 System. For more information on teletext, see the April 1986 issue of **Radio-Electronics.**

However, the Line-21 system, as unsophisticated as it may be, is by far the sturdiest and least expensive system available, and those facts make it ideal for closed-caption use. We call the system "sturdy" because a video signal can be received and decoded under less-than-ideal reception conditions. By contrast, the NABTS system requires a very good signal for operation, and the WST system cannot operate when there is more than slight noise and signal degradation. The Line-21 system, on the other hand, can operate with even an unwatchably noisy or snowy TV signal.

Video encoding

A diagram of the signal that encodes the data is shown in Fig. 1. The data is transmitted on video line 21, which is the last line of the normally-invisible vertical-blanking interval, and it is the line immediately preceding the video image.

To synchronize the decoder's data clock, a seven-cycle burst of a 503-kHz

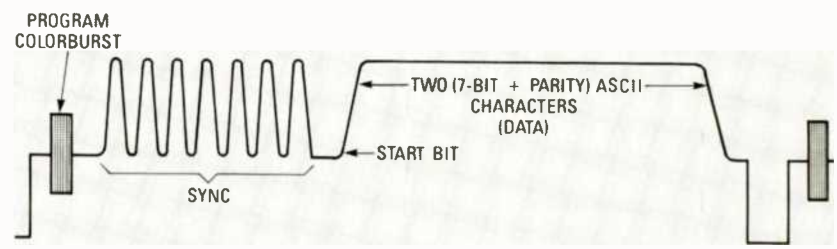


FIG. 1—THE 21ST LINE of each frame of a TV picture contains 17 bits of information. One is a start bit, and two are parity bits. The remaining 14 bits comprise two seven-bit characters of ASCII-like data.

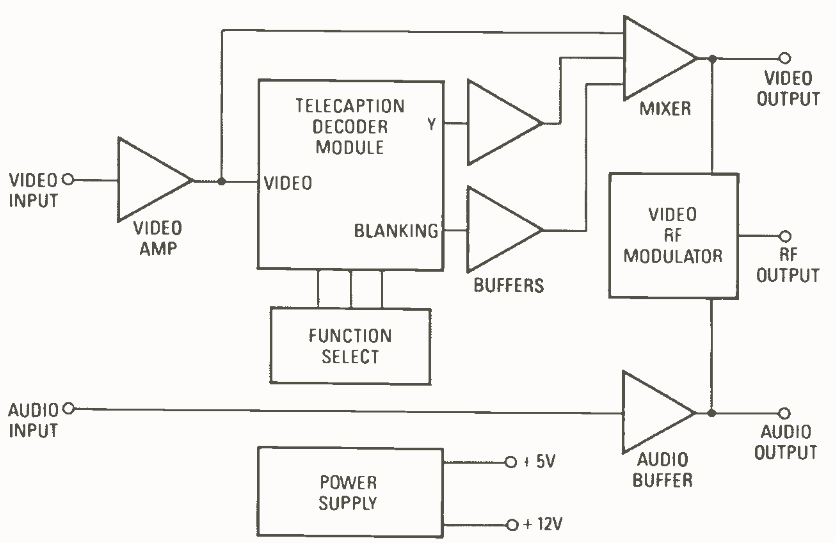


FIG. 2—AFTER BUFFERING, the video signal passes through the decoder module, which extracts the caption data. That data is recombined with the video signal and delivered for output.

signal is transmitted first. That is followed by a start bit and then two seven-bit bytes of data, each of which has an eighth (parity) bit for error detection. That makes a total of 17 bits per frame. So, at 30 frames per second, the overall data rate is 510 bits per second. Although that may seem slow, (particularly when compared with WST's 5.7-megabaud rate), it is fast enough to carry the limited data needed for captions. In addition, it is the slow speed of the Line-21 system that gives it its sturdiness.

Most of the symbols, upper-case, and lower-case letters conform to the standard seven-bit ASCII format. However, there are some 55 special character and control codes in the Line-21 system. Among them are codes that direct the following data to one of the four display channels, codes to position the captions vertically, and codes to position the captions horizontally.

Among the special symbols is a musical note, which is used to indicate the presence of music. The symbol may be present at the beginning, the end, or both of a caption to indicate that the caption is being sung. (And yes, program theme songs and the like are captioned!)

Although captions are currently composed of white characters on a black background, the Line-21 system can provide different background colors, which could be used, for example, to differentiate between speakers on the screen, or simply to provide a more attractive display—which could be particularly effective in the text mode.

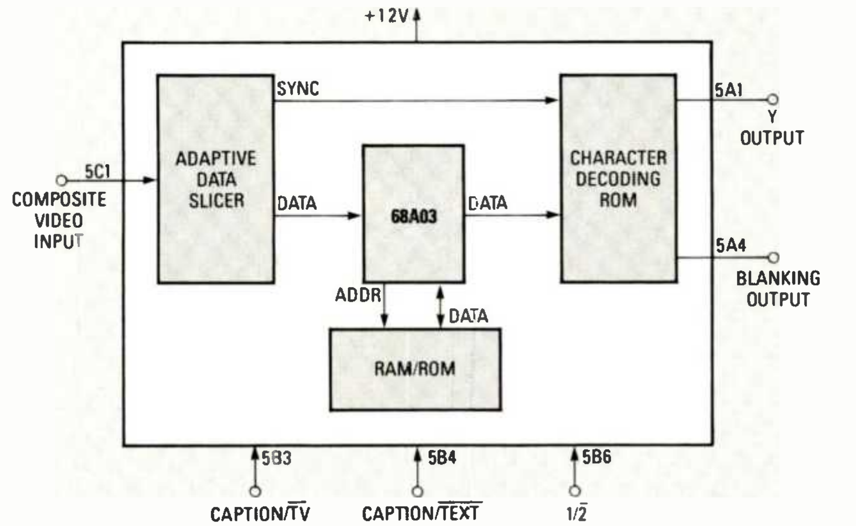


FIG. 3—THE TELECAPTION DECODER MODULE contains a microprocessor, RAM, ROM, and a number of other components that allow it to extract caption and text data from a video signal.

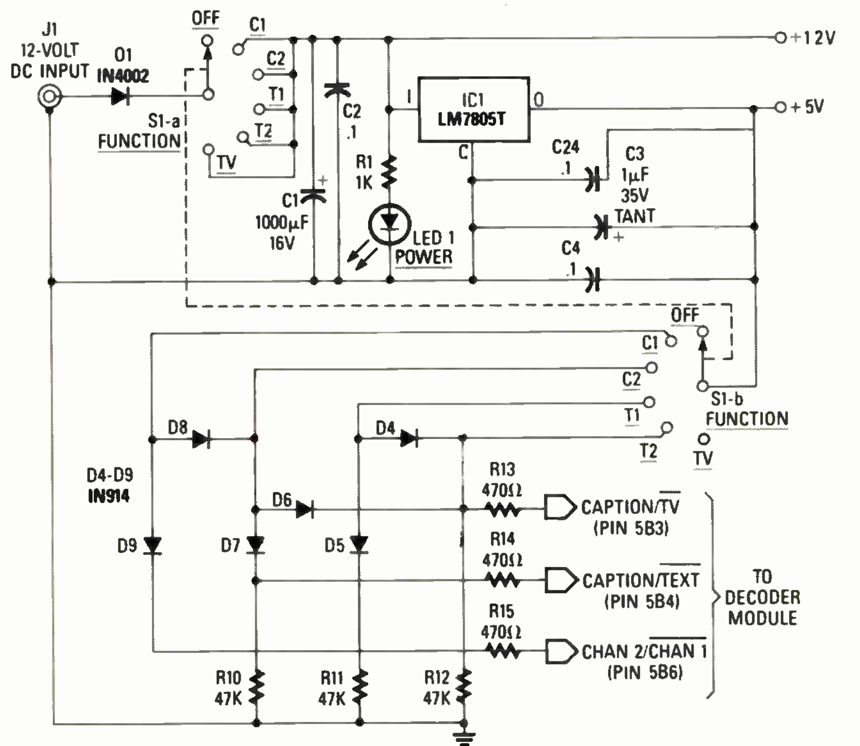


FIG. 4—THE FIVE-VOLT POWER SOURCE supplies power to the NCI decoder module and to the mode-select circuit. The video-mixer circuit in Fig. 5 runs from the unregulated 12-volt supply.

The decoder

A decoder is required at the viewer's end of things to extract the caption or text data from line 21, convert it into displayable characters and backgrounds, and insert those characters into the video signal at the appropriate time.

As you may have guessed, NCI has developed a decoder. The current model, the *Telecaption II*, is priced at $200, is available from Sears and JC Penney's, and incorporates a cable-ready tuner and an IR remote controller. But if you'd like to save some cash and have the satisfaction of building your own—read on!

Circuit description

Since our decoder does not have a built-in tuner, it requires connection to the video and audio outputs of a VCR or other device with audio and video outputs. The decoder in turn has both direct outputs for connection to a VCR or monitor, and an optional RF modulator output that can deliver a signal to either Channel three or Channel four through your TV's antenna-input terminals. A block diagram of the decoder is shown in Fig. 2.

The heart of the device is NCI's Telecaption Decoder Module. The module detects and extracts the caption data, and then converts it for video output. The module is so complete that the only external circuitry required are a power supply, audio and video amplifiers, and the (optional) RF modulator. The module has only six external connections, and it has no internal adjustments or settings. A simplified block diagram of the module is shown in Fig. 3.

The most important portion of the circuitry is the input section, which is called an adaptive data slicer. That circuit locates and locks onto the video data, extracts it, and sends it to the module's controller in digital form. It is termed an adaptive circuit because it can adapt to varying signal, frequency, and noise conditions to extract the data.

Next the data flows to a 68A03 microprocessor where it is processed by a program stored in ROM. If the data is valid, look-up tables in ROM are used to determine the meaning of the data—i. e., whether it is displayable characters or control codes. Then captions are formed

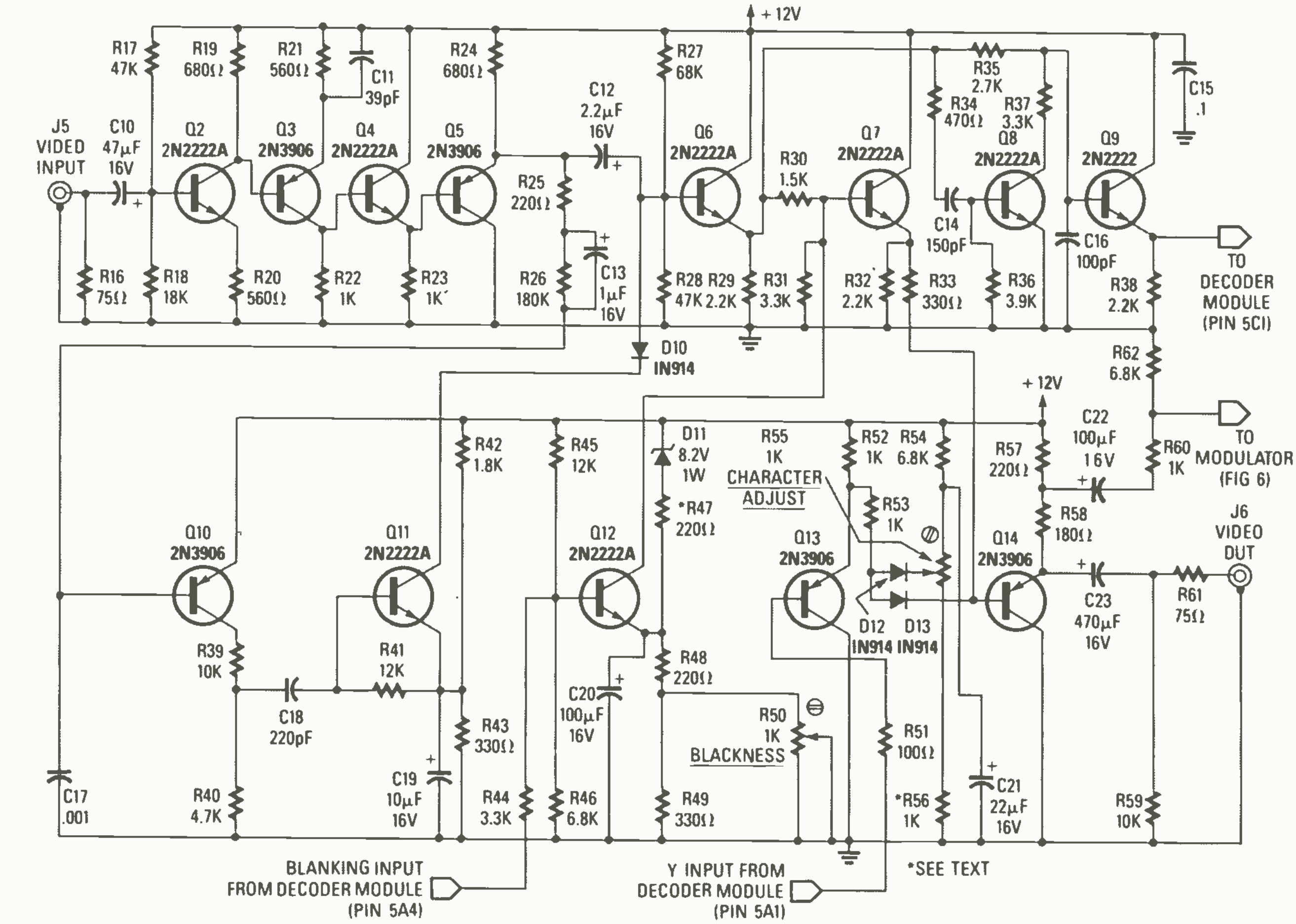


FIG. 5—THE VIDEO MIXER AND BLANKING AMPLIFIER combine the original video signal with the caption data that is extracted from that signal. The result is a baseband video output that can be fed directly to a monitor, VCR, or RF modulator.

and passed on to be re-combined with the original video image.

Although that description makes the job sound easy, a few moments' thought about the complexity of extracting a digital signal from a video signal, interpreting it, converting it, and then inserting the result in sync and in phase with the original image will give you an idea of how difficult the job really is. The 68A03 microprocessor requires 2K of RAM, 12K of ROM, and a 2000-element gate array, some logic IC's, and over 200 passive components to do its job!

Although the module does most of the work, additional circuitry is required to combine text data with the video signal, to provide power, and to select the desired function. Let's look at that circuitry now, starting with power supply and switching circuits, which are shown in Fig. 4.

The decoder is powered by a 12-volt, 500-milliamp wall transformer. Power is routed from jack J1 to FUNCTION switch S1-a via diode D1, which protects the decoder from an accidentally reversed power input. Capacitors C1 and C2 filter the 12-volt input, and LED1 lights up when power is on. IC1 provides a regulated five volts for the NCI module. Because the module draws more than 400 milliamps of current, a heatsink is required to dissipate heat.

The only portion of the non-NCI circuitry that requires five volts is the function-select circuit that is also shown in Fig. 4. The operating mode of the NCI module is determined by the state of the three pins labeled 5B3, 5B4, and 5B6. Incidentally, the module has 6 connectors numbered 5A–5F, and 5D, 5E, and 5F are not used in our decoder.

Pin 5B3 is the CAPTION/$\overline{\text{TV}}$ select input. When that pin is low, the module's decoding functions are inhibited and the video signal is displayed without captions or text. The inputs at the other two pins are also ignored. When that pin is brought high (to +5 volts), the module is placed in decoding mode.

Pin 5B4 is the CAPTION/$\overline{\text{TEXT}}$ select input. When that pin is low, the decoder will seek one of the two text channels; when that input is high, the decoder will seek one of the two caption channels.

Pin 5B6 is the CHAN1/$\overline{\text{CHAN2}}$ select input. It allows you choose between Text Channel 1 and 2, or Caption Channel 1 and 2, depending on the state of pin 5B4. When 5B6 is low, T2 or C2 will be selected. When 5B6 is high, T1 or C1 will be selected. Switch S1-b, in conjunction with resistors R10–R15 and the array of diodes (D4–D9), allows you choose between OFF, C1, C2, T1, T2, or TV.

We have also designed an all-electronic function-select circuit which we'll present next time. That circuit uses several additional IC's, and it provides a more elegant way of choosing which mode the decoder operates in.

Video circuit

Figure 5 shows the bulk of the non-NCI circuit. That circuit has two main functions. First, it provides the module with a clean, buffered composite-video signal from which the caption data can be extracted. Second, it combines the Blanking and Y (character) outputs from the module with the original video signal, thus providing a composite signal composed of both captions and images.

The composite-video signal from J5 is fed to the video buffer composed of transistors Q2–Q5. That signal is then routed via R25, R26, and C13 to a sync separator

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1, R22, R23, R52, R53, R56, R60—1000 ohms
R2—15,000 ohms
R3—270,000 ohms
R4—100,000 ohms
R5—22,000 ohms
R6—390 ohms
R7, R40—4700 ohms
R8, R58—180 ohms
R9, R20, R21—560 ohms
R10–R12, R17, R28—47,000 ohms
R13–R15, R34—470 ohms
R16, R61—75 ohms
R18—18,000 ohms
R19, R24—680 ohms
R25, R47, R48, R57—220 ohms
R26—180,000 ohms
R27—68,000 ohms
R29, R32, R38—2200 ohms
R30—1500 ohms
R31, R37, R44—3300 ohms
R33, R43, R49—330 ohms
R35—2700 ohms
R36—3900 ohms
R39, R59—10,000 ohms
R41, R45—12,000 ohms
R42—1800 ohms
R46, R54, R62—6800 ohms
R50, R55—1000 ohms, PC-mount, trimmer potentiometer
R51—100 ohms

Capacitors

C1—1000 μF 16 volts, electrolytic
C2, C4, C6, C15, C24—0.1 μF, ceramic disk
C3—1 μF, 35 volts, tantalum
C5, C13—1 μF, 16 volts, electrolytic
C7, C8, C19—10 μF, 16 volts, electrolytic
C9, C21—22 μF, 16 volts, electrolytic
C10—47 μF, 16 volts, electrolytic
C11—39 pF, ceramic disk
C12—2.2 μF, 16 volts, electrolytic
C14—150 pF, ceramic disk
C16—100 pF, ceramic disk
C17—0.001 μF, ceramic disk
C18—220 pF, ceramic disk
C20, C22—100 μF, 16 volts, electrolytic
C23—470 μF, 16 volts, electrolytic

Semiconductors

IC1—LM7805T, 5-volt regulator
D1—1N4001, rectifier
D2—not used
D3—1N4735 6.2-volt, 1-watt Zener diode
D4-10, D12, D13—1N914 switching diode
D11—1N4738 8.2-volt, 1-watt Zener diode
LED1—standard red
Q1, Q2, Q4, Q6–Q9, Q11, Q12—2N2222A NPN
Q3, Q5, Q10, Q13, Q14—2N3906 PNP

Other components

J1—⅛-inch miniature phone jack
J2-J6—RCA phono jack
S1—2P6T miniature rotary switch
S2—SPST miniature slide switch

Miscellaneous: Astec UM1285-8 video modulator, NCI Telecaption Decoder Module, PC board, 12-volt 500-ma wall-mount transformer, case, panels, wire, solder, etc.

Note: A kit (no. K-6314) including PC board, case, and all parts except RF modulator and power transformer is available for $139 plus $7.55 shipping and handling from Dick Smith Electronics, Inc., P. O. Box 8021, Redwood City, CA 94063. The modulator (no. K-6040) is available for $9.95 and the power transformer (no. M-9526) is available for $6.95. Allow shipping of $1.50 plus 5% of order. California residents must add 6.5% sales tax. Orders outside the U. S. must include U. S. funds and add 20% of total for shipping.

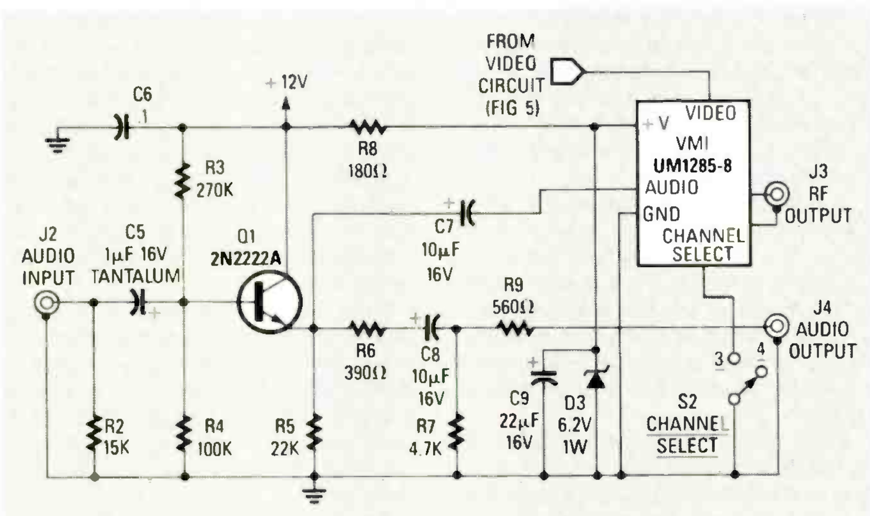


FIG. 6—THE AUDIO BUFFER is a simple emitter follower. Like the video signal, the audio signal can be fed directly to a monitor, a VCR, or the optional RF modulator.

and DC clamp composed of transistors Q10 and Q11. The output of that circuit is then coupled, along with the original signal, to the base of buffer transistor Q6. The output of Q6 drives both blanking transistor Q7 and the output buffer transistor Q9; it is the latter which drives the video input (pin 5C1) of the NCI decoder module.

Between Q6 and Q9 is a noise-cancellation circuit composed of Q8 and the components around Q8. That circuit helps remove impulse noise from the video signal and therefore reduces the module's error rate.

The blanking signal provides the black background for the captions and text. It is produced at pin 5A4 of the module. That signal is buffered and amplified by Q12. The output of Q12 is coupled, along with the original video signal, to the base of blanking buffer Q7. The combined signals are then applied to the base of the video output buffer, Q14.

The blanking "blackness" level is set by components D11 and R47–R49. The level, which is stabilized by C20, can be adjusted by means of rear-panel trimmer potentiometer R50.

The Y (character) output comes through pin 5A1 of the module. It is then buffered and amplified by Q13. The output of Q13 is added to the video and blanking signals at the base of transistor Q14.

Diode D13 prevents any Y level below the blanking level from reaching the output and perhaps disturbing the picture sync.

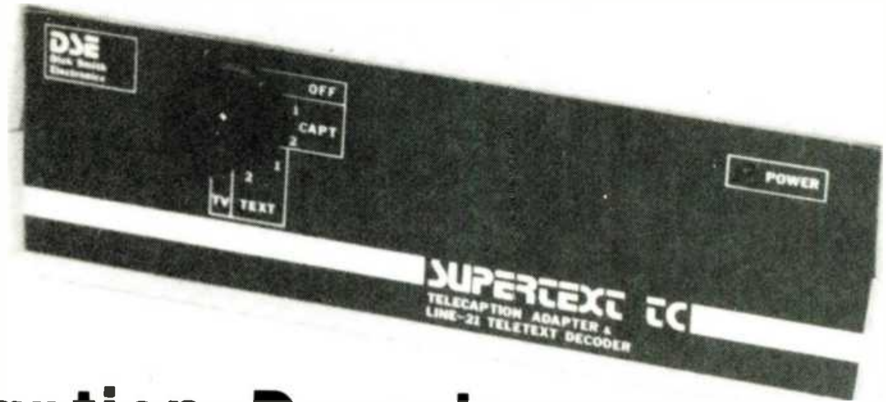
Diode D12 and resistors R54–R56 are used to clip the upper portion of the Y signal and limit the brightness of the characters. The clipping level is set by R55, another rear-panel trimmer.

Output transistor Q14 combines the original video image with the blanked-out boxes and the white captions. That transistor delivers a signal to video output jack J6 and it drives the video input of the RF modulator.

The final portion of the decoder's circuitry is shown in Fig. 6. Since the audio signal plays no part in the caption decoding process, it is merely buffered by Q1 and routed to audio output jack J4 and the audio input of the RF modulator. The latter delivers a standard video signal on either Channel three or Channel four; a switch is provided that allows you to choose the desired channel.

The RF modulator requires a six-volt supply, which is derived from the 12-volt rail by R8 and D3, and which is smoothed and stabilized by C9.

That completes the circuit description of our closed-caption decoder for the hearing impaired. Unfortunately, we have run out of room for this month. When we continue next time we will present complete instructions for building the unit. We will also present the details for the electronic function-select circuit we mentioned earlier. Finally, we'll show how to hook up and use the unit. In the meantime, you may want to get a head start by gathering the required parts. **R-E**



Closed-Caption Decoder

J. DANIEL GIFFORD

Last month we looked at the theory and the circuitry behind the closed-caption decoder. Now let's build one.

Part 2 WHEN WE FINISHED UP last time, we discussed the basics of how closed captioning works, and we presented the complete schematic diagrams of our closed-caption decoder. Now you can warm up your soldering iron—we're ready to build the circuit.

Construction

Building the decoder is fairly easy because it has only a single IC, and because all components, except the switches and power jack J1, mount on the PC board.

The NCI telecaption module, the heart of the decoder, mounts in the bottom of the case, and the PC board mounts in the top. The close quarters in the case require that all components on the PC board be low-profile types with heights less than one inch. The only problem component is the 7805 regulator, which requires a relatively large heatsink. We solved the problem by installing a vertical-mount heatsink horizontally.

To begin construction, first inspect the PC board (whether you make your own or buy the kit) for plugged holes and broken or shorted traces. Fix any and all faults before proceeding.

Following the component-placement diagram in Fig. 7, install the three jumpers using 22-gauge bus wire. Keep the jumpers tight and flat against the surface of the board to prevent shorts. Next, insert 26 PC pins into the holes in the board where wires will connect: 15 along the right edge of the board (where the NCI module will connect), two for J1, two for S2, and seven for S1. Turn the board over carefully and rest it on the pins while you solder them in place.

Next install the 59 fixed-value resistors. The holes for all the resistors are spaced so that the leads of each resistor can be bent right at the body. To ease troubleshooting, mount the resistors so that the color codes point the same way.

Install the capacitors, taking care to orient the polarized electrolytic and tantalum types correctly. Keep all the capacitors as close to the board as possible, bending their leads if necessary to match the hole spacing.

Install the diodes next, taking care both to orient them correctly and not to mistake the different types. In particular, be certain that the 6.2-volt Zener is inserted in the D3 position, and that the 8.2-volt Zener goes in the D11 spot. Use care in bending the leads of the diodes, particularly the glass types.

Now install the transistors. To avoid mixing up the two types, first insert and solder the five PNP devices (Q3, Q5, Q10, Q13, and Q14). Then insert the nine NPN transistors in the remaining positions, and solder them in place. Keep the transistors close to the board—their cases should be no more than ¼ inch from its surface.

Press the four RCA jacks (J2, J4, J5, and J6) into the board and bend their tabs over to hold them in place. Check that they are all firmly and squarely seated, then solder them in place, using a fair amount of solder to obtain firm joints.

Insert the two trimmer resistors, R50 and R55, into the board and solder them in place. Be certain that they are well mounted, so that repeated adjustments will not work them loose.

Press the RF modulator into the board and twist its lugs to hold it in place. Solder the lugs to the foil, using plenty of solder to make a secure joint. Not only do the lugs hold the relatively heavy modulator in place, but they are used as jumpers to extend the ground plane to two points near the center of the board. Poor mounting will cause problems. Insert the modulator's four leads into their holes, noting that they angle back from the edge of the board slightly. Pull the leads tight, then solder them.

Now install the 7805 regulator and its heatsink. The heatsink supplied with the kit has two pins extending from one end to facilitate vertical mounting. Since the heatsink will be mounted horizontally, remove the pins with a pair of pliers.

Insert the 7805 regulator into the board with its metal tab toward C1, and then bend it so that the hole in its tab lines up with the hole in the board. DO NOT solder its leads yet.

Pass the heatsink's mounting screw through the PC board and through several metal washers to hold the regulator slightly above the board. Apply a layer of heatsink compound to the back of the 7805 and attach the heatsink, tightening the screw firmly. Solder the regulator's leads now.

The last step in building the PC board is to mount power-on indicator LED2. It must extend from the edge of the PC board to meet its mounting hole in the front panel. The easiest way to determine its mounting position is to temporarily fit the

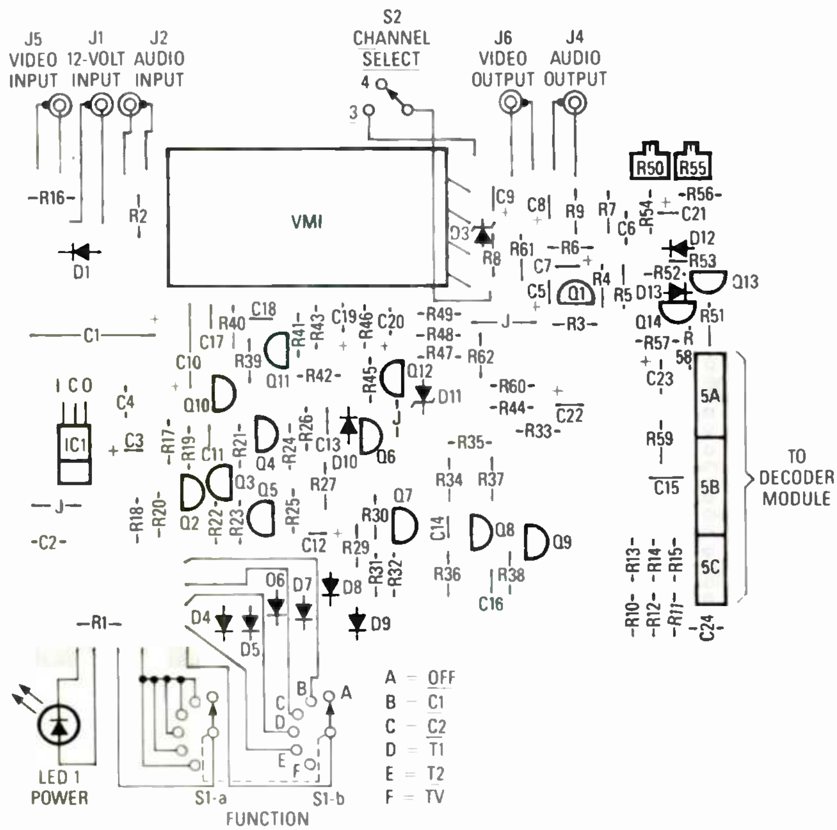


FIG. 7—MOST COMPONENTS EXCEPT THE SWITCHES AND J1 mount on the PC board. Use PC-board pins to connect the off-board components.

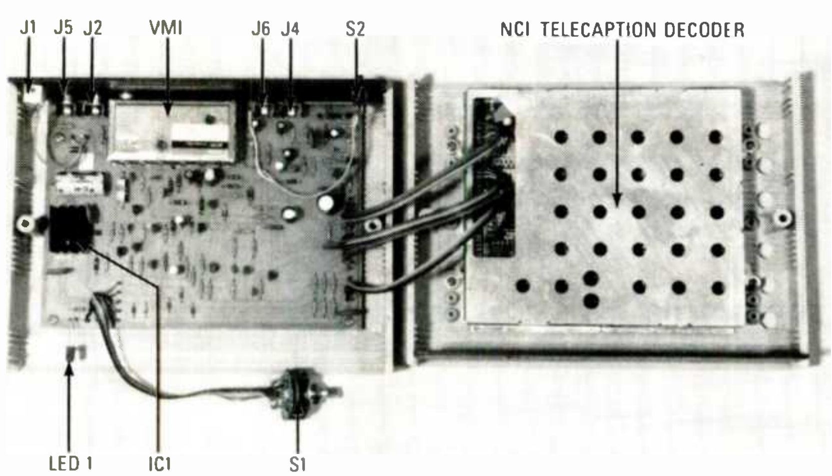


FIG. 8—THE PC BOARD MOUNTS IN THE BOTTOM of the case and the NCI decoder module mounts in the top. Make sure that the three jumper cables connecting the PC board and the module are oriented correctly.

PC-board and the front panel into the case. After the LED's leads are bent to fit, remove the board and solder the LED in place. Note that the lead next to the flat edge of the LED's case goes to the hole nearest the corner.

After all components have been mounted, inspect your work for incomplete joints and solder bridges, and correct any problems. Clean flux from the bottom of the board, and then spray it with an acrylic dielectric spray. Doing so will help the decoder to remain trouble-free in changing humidity conditions.

Interconnections

The connectors that couple our board to the NCI module are an unusual type with 0.1" spacing between adjacent pins. They are insulation-displacement types, so you need only press a strand of ribbon cable into each contact. We use three connectors of different sizes: four-, five-, and six-contact points. Each interconnecting cable has a connector only at the end that attaches to the NCI module; the other end is soldered to the PC board.

Cut three pieces of ribbon cable about six or seven inches long, one each with four, five, and six conductors, and separate the conductors about one inch at each end. Insert the unstripped wires into the "bays" of the appropriate connector and, holding them in place, pull the cable down across the terminals, but don't apply too much pressure. With the cable seated, use a small flat-blade screwdriver to push each wire into the notch of its terminal.

Strip about ¼-inch of insulation from the other end of each conductor of all three ribbon cables. Twist the strands together, and then solder the wires to the PC-board pins. Make sure that you solder those wires so that the connectors at the other end will be able to fit in the NCI module. Figure 8 shows how they should seat. The six-conductor cable should be split for an inch or so at the PC end between its second and third conductors in order to clear C15. Or you could push C15 so that it lies flat on the board. Don't break its ceramic coating or short any of the other connnecting pins. After all of the wires are soldered in place, inspect your work and correct any errors.

Attach J1 and S2 to the rear panel, and insert the panel into the top half of the case. Install the PC board and secure it with four self-tapping screws. Make sure that the jacks line up with the holes in the panel.

Connect wires between J1's pins and the appropriate pins on the PC board. Then connect S2 to the channel-select pins, using segments of ribbon cable or other 20- to 24-gauge hookup wire. Keep the wires short and neat, but leave a small amount of slack to allow removal of the board or the panel.

Remove the anti-rotation lug from rotary switch S2 and mount the switch to the front panel, tightening its nut finger-tight. Fit the knob to the shaft and adjust the switch's position so that the knob's indicator lines up with the panel markings. Carefully remove the knob and tighten the nut. Then re-install the knob and make sure that the indicator still lines up.

Use bus wire to connect the five common terminals of S1-a together. Clip the terminals off just above the wire, and re-

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.
R1, R22, R23, R52, R53, R56, R60—1000 ohms
R2—15,000 ohms
R3—270,000 ohms
R4—100,000 ohms
R5—22,000 ohms
R6—390 ohms
R7, R40—4700 ohms
R8, R58—180 ohms
R9, R20, R21—560 ohms
R10–R12, R17, R28—47,000 ohms
R13–R15, R34—470 ohms
R16, R61—75 ohms
R18—18,000 ohms
R19, R24—680 ohms
R25, R47, R48, R57—220 ohms
R26—180,000 ohms
R27—68,000 ohms
R29, R32, R38—2200 ohms
R30—1500 ohms
R31, R37, R44—3300 ohms
R33, R43, R49—330 ohms
R35—2700 ohms
R36—3900 ohms
R39, R59—10,000 ohms
R41, R45—12,000 ohms
R42—1800 ohms
R46, R54, R62—6800 ohms
R50, R55—1000 ohms, PC-mount, trimmer potentiometer
R51—100 ohms

Capacitors
C1—1000 µF 16 volts, electrolytic
C2, C4, C6, C15, C24—0.1 µF, ceramic disk
C3—1 µF, 35 volts, tantalum
C5, C13—1 µF, 16 volts, electrolytic
C7, C8, C19—10 µF, 16 volts, electrolytic
C9, C21—22 µF, 16 volts, electrolytic
C10—47 µF, 16 volts, electrolytic
C11—39 pF, ceramic disk
C12—2.2 µF, 16 volts, electrolytic
C14—150 pF, ceramic disk
C16—100 pF, ceramic disk
C17—0.001 µF, ceramic disk
C18—220 pF, ceramic disk
C20, C22—100 µF, 16 volts, electrolytic
C23—470 µF, 16 volts, electrolytic

Semiconductors
IC1—LM7805T, 5-volt regulator
D1—1N4001, rectifier
D2—not used
D3—1N4735 6.2-volt, 1-watt Zener diode
D4–10, D12, D13—1N914 switching diode
D11—1N4738 8.2-volt, 1-watt Zener diode
LED1—standard red
Q1, Q2, Q4, Q6–Q9, Q11, Q12—2N2222A NPN
Q3, Q5, Q10, Q13, Q14—2N3906 PNP

Other components
J1—⅛-inch miniature phone jack
J2–J6—RCA phono jack
S1—2P6T miniature rotary switch
S2—SPST miniature slide switch
Miscellaneous: Astec UM1285-8 video modulator, NCI Telecaption Decoder Module, PC board, 12-volt 500-ma wall-mount transformer, case, panels, wire, solder, etc.

Note: A kit (no. K-6314) including PC board, case, and all parts except RF modulator and power transformer is available for $139 plus $7.55 shipping and handling from Dick Smith Electronics, Inc., P. O. Box 8021, Redwood City, CA 94063. The modulator (no. K-6040) is available for $9.95 and the power transformer (no. M-9526) is available for $6.95. Allow shipping of $1.50 plus 5% of order. California residents must add 6.5% sales tax. Orders outside the U. S. must include U. S. funds and add 20% of total for shipping.

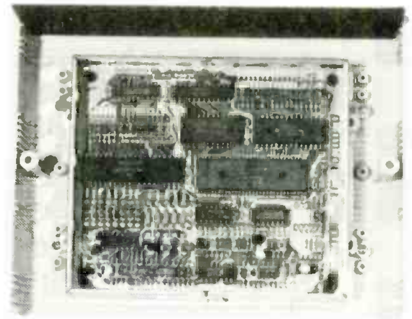


FIG. 9—THE NC1 MODULE, shown here with its cover; remved, mounts to the bottom of the case.

move the OFF terminal completely. The terminals must be removed in order for the switch to clear the edge of the PC board. To prevent possible wiring errors, remove the two terminals corresponding to the OFF and the TV positions of S1-b.

Solder a six- to seven-inch length of seven-conductor ribbon cable to the pins near the front of the PC board. Connect the other end to the appropriate points of S1. Insert the front panel into the top of the case.

Drill a row of ⅜-inch cooling holes along the bottom of the left half of the case. Those holes will let air get in to cool the heatsink; waste heat will pass by convection through the gaps around the rear-panel jacks.

Next mount the NCI module in the bottom half of the case. The module has four mounting lugs designed for attachment to a flat surface. To mount the module to the standoffs in the bottom of the case, bend the lugs so that they extend straight out from the module's shielding can; then make an additional horizontal bend about ¼ inch from the first bend. Press the module into place with the connectors on the opposite side of the cooling holes, and with the rear edge against the slot for the rear panel. The module must be all the way back to provide room for the rotary switch in front. Secure the module in place using self-tapping screws and washers. Do not connect the module to the PC board yet.

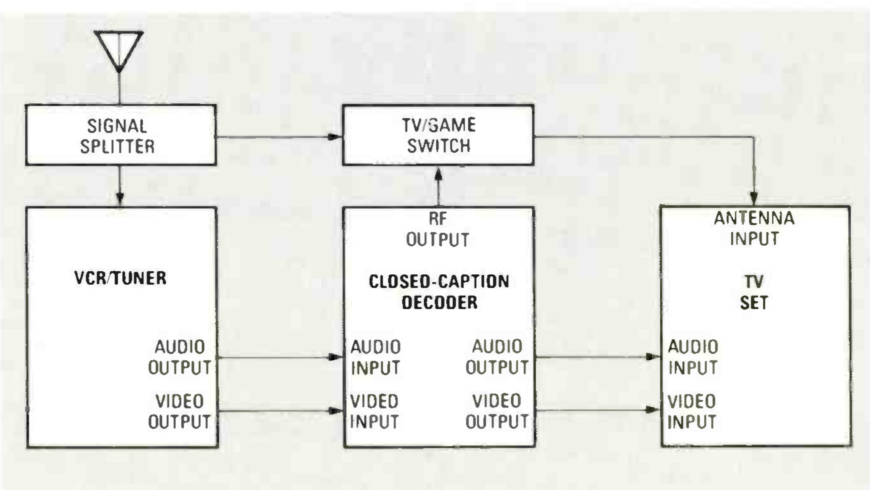


FIG. 10—SYSTEM WIRING DIAGRAM shows how the decoder should be connected to your video system. The signal splitter and TV/GAME switch are optional.

Testing and adjustment

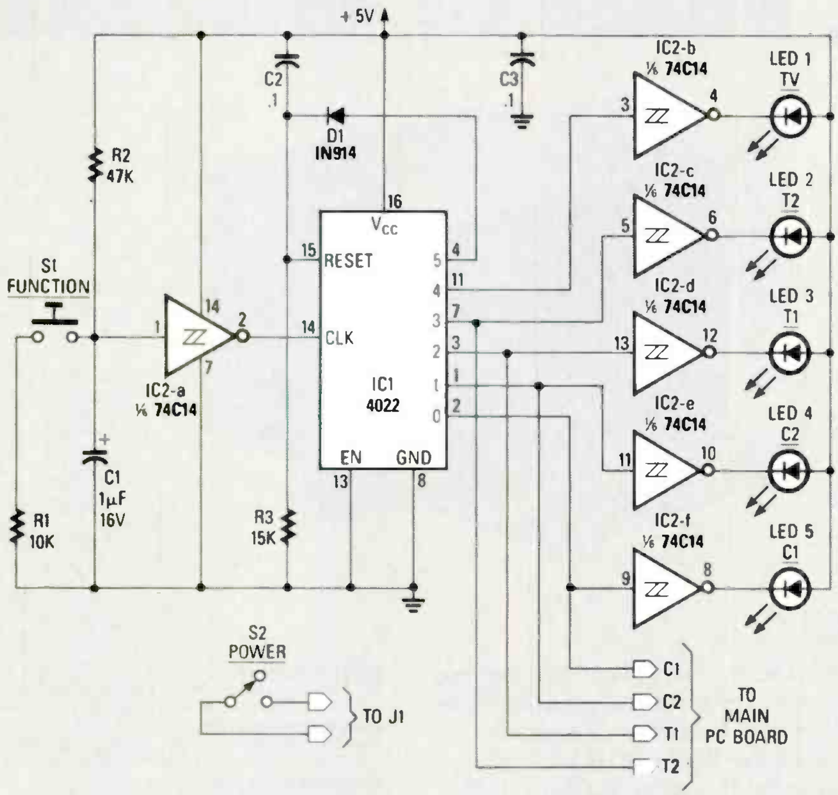
Turn the rotary switch to OFF and plug the wall transformer's output plug into the power jack. Then plug the transformer into an AC socket and turn S1 to CI. LED1 should light up. Turn the knob through the other positions; the LED should remain lit.

Measure the voltage at the positive lead of C1. It should be no less than 12.5 and preferably no more than 16 volts. (That voltage will drop when the heavy load of the module is added.) Measure the 5-volt supply at either the +5 volt pin of S1-b or at module connector pin 5C4. It should be within 0.25 volt of 5 volts. Finally, measure the voltage at the cathode of D3; it should be between 5.8 and 6.2 volts. If all voltages are correct, turn the decoder off and attach the connectors to the NCI module. Turn the power back on.

Again measure the voltage at the positive end of capacitor C1. Ideally, it should be between 12 and 12.5 volts, but it may vary, depending on the wall trans-

ELECTRONIC FUNCTION SELECTOR

As promised last month, we'll describe an all-electronic function-selector circuit that can be used to replace the rotary function selector, S1. The circuit is shown in Fig. 1.



clock input; that pulse advances the counter by one. The 0 output goes low and the 1 output (pin 1) goes high, so the C2 LED lights up, and caption channel C2 is selected. Successive presses of S1 cycle

The heart of the circuit is a 4022 8-stage ring counter. In a ring counter, one and only one output is high at any time. Each output of the 4022 drives an LED via an inverter. The first four outputs are also connected to the corresponding inputs on the main PC board. When power is first applied, C2 and R3 reset the counter, so the 0 output (pin 2) is high. Therefore, the decoder comes up tuned to the most popular closed-caption channel, C1.

When S1 is pressed, a pulse is applied (via Schmitt trigger IC2-a) to the counter's the 4022 through each of its states; a fifth press returns the decoder to the C1 mode, because the output 5 (pin 4) is coupled to the RESET input via diode D1.

You can build this circuit on a piece of perfboard and attach it to the front panel with spacers and screws. Note that a separate SPST switch will then be required to switch the decoder's power on and off; in addition, power-on indicator LED1 (on the main board) can be omitted, since one of the function LED's will light up whenever the power is on. **R-E**

PARTS LIST— ELECTRONIC FUNCTION SELECTOR

R1—10,000 ohms
R2—47,000 ohms
R3—15,000 ohms
C1—1 µF, 16 volts
C2, C3—0.1 µF
IC1—4022 ring counter
IC2—74C14 hex Schmitt trigger
D1—1N914
LED1-LED5—Standard
S1—SPST normally open pushbutton
S2—SPST toggle

former used. To accommodate transformers with various output voltages, it may be necessary to alter the values of several resistors. We'll discuss those modifications in a moment.

Before closing up the case, temporarily connect the decoder to your video system as shown in Fig. 9. Note that a video switch is shown in that figure: it can be used to bypass the decoder when caption decoding is not needed. If captions will be desired most or all of the time, the switch, and the signal splitter, can be omitted and the decoder's TV mode can be used to bypass decoding, if necessary.

Select a strong station on the VCR or tuner, set your TV and S2 on the decoder to Channel 3 or 4. Now turn everything on. Place S1 in the TV position.

If the picture and sound on the TV are good, then no adjustments to the modulator are necessary. But if either picture or sound is faulty, use a ¹⁄₁₆-inch flat screwdriver to adjust the modulator's tuning coil (the one nearest the input leads) until the picture is good. Then adjust the other coil until the sound is clearest. You may have to adjust both coils several times to optimize both audio and video.

Set trimmer resistors R50 and R55 to the center of their travels, set S1 to C1, and tune in a captioned program. During the day, the best place to find one is on a PBS station. At night, try either a PBS or an ABC station. On satellite, tune in any of the ABC or PBS feed transponders.

If the captions appear with a dark background and bright, legible characters, no adjustments are necessary. But, if the boxes are too light, if the captions distort the picture, or if dark streaks appear in light scenes, adjust the BLACKNESS control (R50) until the boxes are as dark as they will get without streaks or distortion. If the characters are either too dim or smeared, adjust the CHARACTER control (R55) until they are clearly visible, but not smeared.

If proper adjustment cannot be obtained in the middle 1/3 of the trimmer's travel (or cannot be obtained at all), the problem is most likely the 12-volt supply. To compensate, one or two of the resistors in the blanking and Y level bias circuits will have to be changed. The resistors should be changed only if it is difficult to get clear captions and background.

If the background will not adjust properly, clip R47 from the board, leaving the lead stubs in place. Connect a 1K trimmer resistor to the stubs and, with the background trimmer set to the center of its travel, adjust the new resistor to obtain a dark background without streaks or distortion. Turn the decoder off, measure the value of the pot, and replace it with the closest standard resistor. If you're careful, you can solder the new resistor to the leads of the old one without having to remove the board from the case.

If it is the characters that will not adjust properly, perform the same procedure, but substitute a 2K trimmer resistor for R56.

After everything is working correctly, disconnect the decoder, assemble the case, and reconnect it to your video system. Now you're ready to enjoy the new world of closed-caption programming.

To conclude, it's our sincere hope that all of the hearing-impaired persons who are aided by this project enjoy using it as much as the author enjoyed designing and developing it and we enjoyed publishing it. It was truly our pleasure. **R-E**

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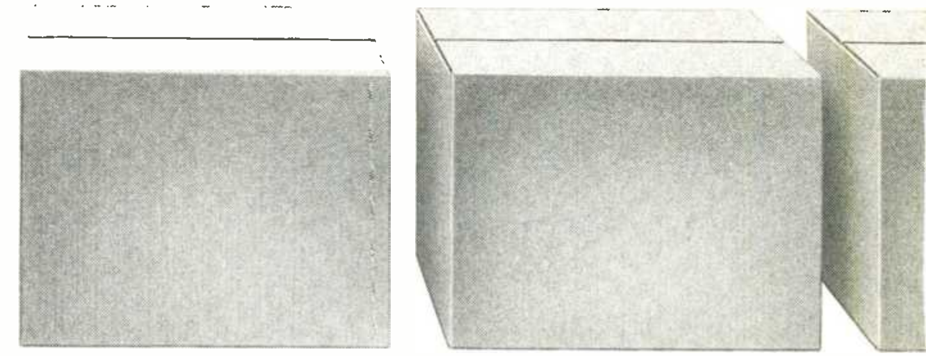

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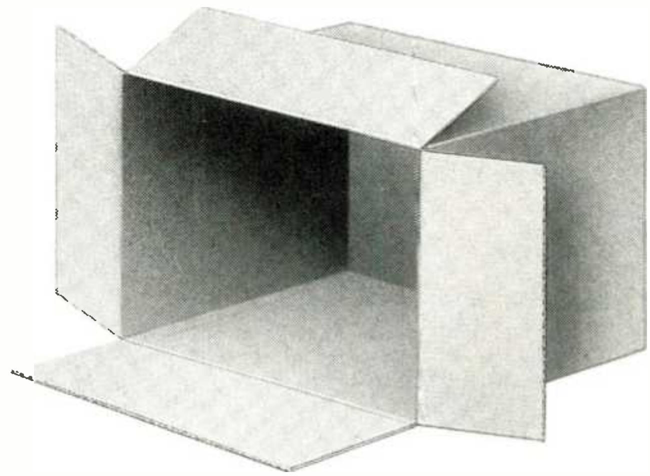

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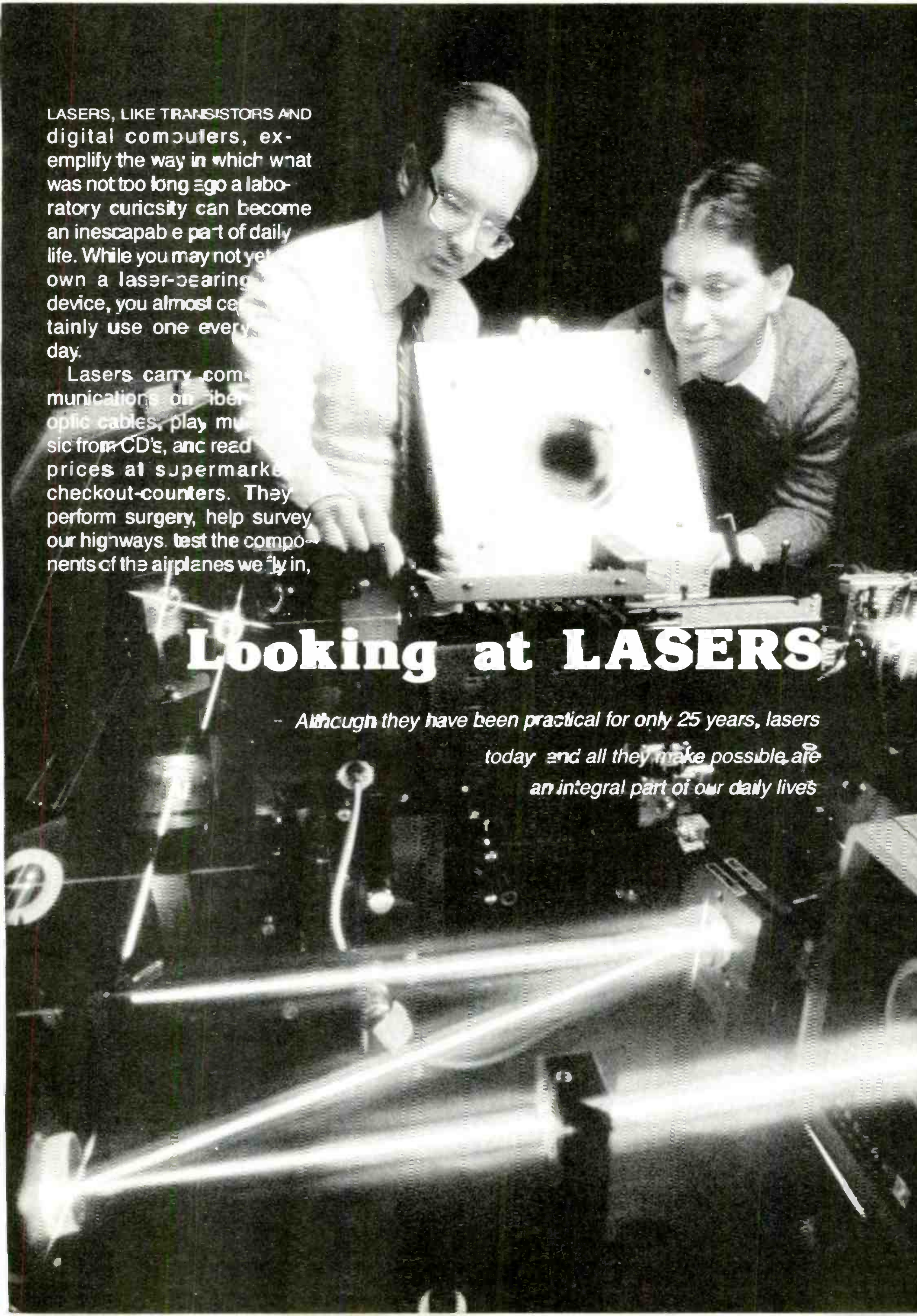


Looking at LASERS

Although they have been practical for only 25 years, lasers today and all they make possible are an integral part of our daily lives

LASERS, LIKE TRANSISTORS AND digital computers, exemplify the way in which what was not too long ago a laboratory curiosity can become an inescapable part of daily life. While you may not yet own a laser-bearing device, you almost certainly use one every day.

Lasers carry communications on fiber-optic cables, play music from CD's, and read prices at supermarket checkout-counters. They perform surgery, help survey our highways, test the components of the airplanes we fly in, and entertain us at rock concerts. They also make formidable weapons.

What is a laser?

A laser (which stands for *L*ight *A*mplification by *S*imulated *E*mission of *R*adiation) is a source of intense light that has several unusual and useful properties. The light is monochromatic, which means that it is a single, very pure, color whose frequency can be measured and used as a precision standard in and out of the laboratory. Laser light is coherent—all the waves of a beam are in phase. Unlike natural and most artificial light sources, whose emissions are incoherent, or phased randomly, a laser produces packets of photons all "marching in step", and possessing a great deal of energy. Finally, because of the way they are generated the rays of light produced by a laser are all parallel to one another, or very nearly so. A pencil-thin beam of laser light aimed at the moon will spread out to a diameter of only 1½ miles. That may not sound impressive—until you consider that the light would travel a distance of about 250,000 miles before diverging that far.

How lasers work

The principle behind the laser is called stimulated emission. That term refers to the fact that an atom, when in an excited state, can be made to emit a photon when bombarded by other photons or by another high-energy source such as a source of electrons.

That needs a little explaining. Figure 1-*a* shows a simple hydrogen atom—just a proton and an electron. The "height" of the orbit of the electron depends on the amount of energy that the electron is carrying and is very strictly defined by nature. Further, for an electron to be forced to jump from one orbit to another requires a precise amount of energy, or quantum, to be added to it.

In its lowest orbit, no energy has been added and the electron is in its normal, or ground, state. When just the right amount of energy is applied, the electron will jump to a higher orbit, and it is said to be excited (Fig. 1-*b*). That excited state, though, is unstable, so the electron quickly returns to its ground state. When it does that it gives up the energy that was applied to it, in the form of a photon, or particle of light. (Light is electromagnetic radiation but it frequently behaves like a particle. For that reason, a photon is sometimes called a "waveicle.") That spontaneous emission of photons is where laser light begins.

If you get enough excited atoms together, spontaneously emitting photons as they undergo the transition from the excited to the ground state, an interesting thing happens. When one of those photons strikes an already excited atom, it changes state and emits its own photon (Fig. 1-*c*).

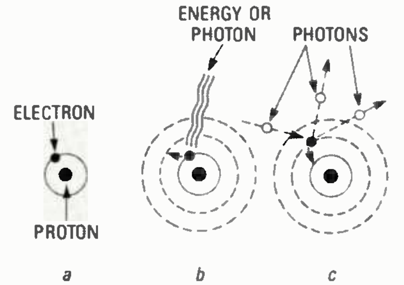


FIG. 1—A SIMPLE HYDROGEN ATOM is shown in a. If a precise amount of energy, or quantum, is added to the atom (*b*), the electron makes a transition from its normal ground state to a less-stable excited state and jumps to the next higher orbit. If a photon strikes the electron while it is in that excited state, the electron will return to the ground state and emit a photon of its own (*c*).

Thus, there are then two photons where previously there was one. Those two photons can go on to strike other excited atoms and generate still more photons—a process very much like what happens in a nuclear-fission reaction. That process of photons generating other photons from excited atoms is known as stimulated emission. A photon of a particular wavelength gives rise only to photons of the same wavelength. Thus, laser light is monochromatic; it contains only a single color.

The trick, of course, is to get together in one place a large number of excited atoms of the same kind, so the that stimulated emission of photons can take place. That is done by pumping the atoms in a material up to an excited state by bombarding them with intense light or with some other source of energy such as a beam of electrons. With a ruby laser—the type used by Theodore Maiman on July 7, 1960 when he demonstrated the first laser—as an example, let's examine the lasing process.

A simple diagram of a ruby laser appears in Fig. 2. The heart of that device is a rod of synthetic ruby whose ends are finely ground and polished so they are optically flat and are exactly parallel to one another. Both ends of the rod are silvered to reflect light back into it, but the reflecting surface at one end is not a perfect reflector—it allows perhaps ten percent of the light generated within the rod to escape. That light is the laser beam.

The rod is surrounded by a spirally-wrapped xenon flash tube similar to those used in electronic flash-units. The light produced by that tube will excite the atoms in the ruby rod. Because of that, that type of laser is known as an optically pumped laser. (As we shall see, there are other types of excitation commonly used.) The cooling equipment is present to remove the heat generated by the lasing device. Lasers are extremely inefficient—only one or two percent of the power they consume is transformed into usable laser light; the rest is given off as ordinary light and lots of heat. That isn't really too bad though—an ordinary incandescent bulb is only about two percent efficient, and the light it produces can't begin to compare with that from a laser.

When the flash tube discharges, the photons it emits enter the ruby rod through its sides and excite the material's chromium atoms, which absorb green and blue light. (Those atoms are what give the ruby its reddish color; you may remember from physics that whatever light a material doesn't reflect or transmit, it absorbs.) When those excited atoms decay from their excited state they give off photons, which trigger other excited atoms to release photons, and so on. The whole process in a ruby laser takes place in about 300 microseconds, and an intense burst of ruby-red light is produced.

We now have lots of light, but we still don't have a laser. That's where the reflective end surfaces of the rod come in. Most of the red light generated within the rod escapes through the sides, but some of it is reflected back into the rod, and that gives rise to the stimulated emission of more red light (hence the "amplification" in the word "laser").

A portion of the light is not reflected, however, but escapes from the rod through the end that is only partially silvered. That

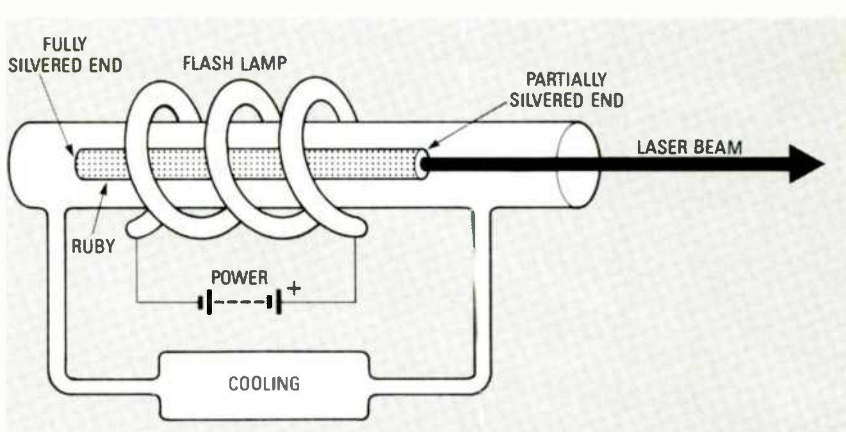


FIG. 2—IN THIS OPTICALLY-PUMPED LASER the light produced by a xenon flash lamp is used to excite the atoms in a ruby rod.

is the laser beam. It is monochromatic because the photons that trigger stimulated emission give rise only to photons like themselves. It is also coherent—all the light waves are in phase. That, too, is a result of the process of stimulated emission; the phase of the photons generated is identical to that of the stimulating photon. The rest of the light reflected by the rod's mirrored ends bounces back to interact with more chromium atoms and produce more photons.

Figures 3-*a* and 3-*b*, respectively, represent coherent and incoherent (random phase) light. As is the case with any wave phenomenon—we're now considering photons as waves rather than as particles—out-of-phase waves tend to cancel each other. Because all the waves of a laser beam are in phase, it is much more intense and powerful than a beam of ordinary incoherent light.

Finally, all of the photons in a laser beam travel parallel to one another. That is the result of the orientation of the reflecting surfaces at the ends of the lasing element. The beam of even an inexpensive laser has a divergence of only about one-twentieth of a degree, which means that the energy it carries is not diffused appreciably over distance.

There are many, many types of lasers, and their characteristics and modes of operation tend to overlap. The following examples are just a small cross section of what has been developed in the past 25 years.

Crystal lasers

This is the category to which the original ruby laser belongs. Those lasers are optically pumped and have a relatively low-power output, in the milliwatt range. The most common type is the neodymium-YAG (for *Y*trium-*A*luminum-*G*arnet) laser, which emits light in the near-infrared. YAG lasers can be operated continuously because the material from which they're made conducts heat, which would otherwise destroy the laser rod, relatively well.

Another member of the crystal-laser family is the neodymium-glass laser. It is less expensive to produce than the YAG type (glass is cheaper than garnet, even the synthetic kind), but it must be pulsed, or operated on a one-shot basis. It cannot sustain continuous operation because of glass's poor heat conductivity.

Gas lasers

There are more gas lasers than there are any other type. Over 5000 types of laser activity in gases are known. Gas lasers are not usually optically pumped, but are energized by passing an electric current at a potential of several thousand volts through the gas, which is contained in a tube with polished and silvered faces similar to the ends of the ruby rod described earlier. As

FIG. 3—IN LASER LIGHT, all of the waves are in phase; thus they are said to be coherent (*a*). In normal light, the waves have no phase relationship (*b*).

the current flows through the gas, the electrons transfer some of their energy to it, bringing it to a state where the stimulated emission of photons can occur. Because of the way they're constructed, gas lasers can be cooled more efficiently than crystal types, and lend themselves better to continuous operation.

The most widely used gas laser is the helium-argon laser, which can be built for a modest sum by almost any experimenter. It is able to produce no more than 50 milliwatts, but its tight beam of red light, about a millimeter across, makes it ideal for laboratory and experimental use.

Argon and krypton lasers can produce a wide range of colors, but are still relatively low in power. It is not feasible, for example, to construct an argon laser more powerful than 100 watts. Argon lasers with their green light are frequently used in medical applications.

The infrared carbon-dioxide laser is more of a heavyweight. It can have an output as high as several hundred kilowatts. Moderate-sized lasers of that sort are widely used in industry.

Liquid lasers

Organic dyes dissolved in organic compounds such as alcohol can be made to lase, too. Organic lasers are unusual in that one laser can produce a wide range of colors. That spectrum can be optically tuned, and a very precise selection of light of a single color can be made. That capability makes the dye laser a very valuable laboratory tool.

Semiconductor lasers

Semiconductor lasers (Fig. 4) are members of the LED family. They differ from ordinary LED's in that they consume considerably more current and the edges of the semiconductor die are polished to form interior reflecting surfaces. Because of their extremely small size—about as big as a grain of salt—and the difficulty of removing the heat they generate, those lasers do not have a very high output. Still, there are many applications to which they are well suited, among them fiber-optic communications and compact-disc players.

Laser applications

In the 25 years since they came into existence, lasers have proven themselves invaluable in a diverse range of fields. Here are a few of them:

Industry: The high temperatures produced by focused laser beams make them excellent tools for welding, cutting, and drilling. A pinpoint of coherent light can cut or bore much more cleanly than its mechanical equivalent, with much less waste. (An informal, and entirely unofficial, system for rating the strength of lasers measures their power in terms of "Gillettes"—the number of razor blades that a beam of laser light can successfully punch through.)

Photographs taken by laser light can be used to determine stress regions and faults

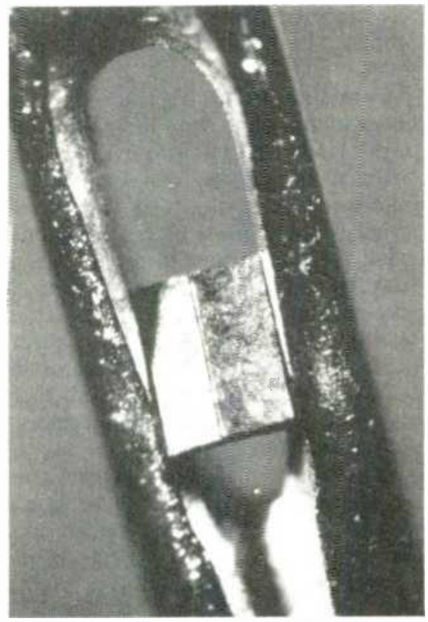


FIG. 4—THIS SEMICONDUCTOR LASER is so tiny that it can fit in the eye of an ordinary sewing needle. Photo courtesy of ATT Bell Laboratories.

in materials, simplifying and improving quality control procedures in critical applications. Lasers are also used in industry for non-contact monitoring of a wide variety of systems. See Fig. 5.

Medicine: Lasers find applications in numerous areas of medicine, among them dermatology, gynecology, and many areas of surgery. The finely focused beam of a laser can operate in areas (such as the inside of the eye) inaccessible to the traditional scalpel.

Science: Lasers have helped scientists both to refine existing knowledge and to learn more about our universe. Using lasers, it has been possible to determine

FIG. 5—LASERS HAVE many applications in industry. Here's a device that uses a laser to monitor the performance of an ultrasonic wire bonder, which is used in electronics production.

the speed of light (186,282.398 miles/second; 299,792.458 kilometers/second) with an accuracy hitherto unknown, and other units of measures have also benefited. A laser beam follows what must be the world's straightest line, a boon for surveyors and the like. Lasers in the laboratory have also allowed the development of new techniques to perform tasks that were previously impossible. Nuclear fusion reactions making possible the generation of enormous quantities of inexpensive electricity from plain seawater will probably be initiated and sustained by lasers.

Communications: Right now fiber-optic communications links using semiconductor lasers are in limited use, but their potential for carrying vast quantities of information makes it certain that as new installations are made, they will become much more common. In space, where laser light cannot be attenuated by air, it may carry communications and data from satellite to satellite, or even to earth. Lasers also are the heart, of course, of the laser printers; those devices, with their high-quality outputs, are now becoming popular in computer circles.

Entertainment: Laser-light shows are popular at rock concerts, and lasers are also used to record and read the information contained on CD's and most videodiscs. Holography, practical only with laser light, makes possible 3-D photography without a camera or special viewing device, and has given birth to a new art form. One day we may enjoy holographic movies, although holographic television at this point seems rather farfetched because of the limited resolution of even the most sophisticated video systems. The applications of holography, of course, are not limited to the world of entertainment. Holographic techniques are also used in devices like scanners for UPC (*U*niversal *P*roduct *C*ode) readers in stores, and in the restoration of artwork.

War: Like dynamite, lasers can be put to both peaceful and destructive uses. Currently in the headlines is the "Star-Wars" technology that will take the science of war into the peace of space. Lasers are also used in the navigation systems of missiles and in targeting devices.

New uses for the unique qualities of laser light are constantly being conceived. Among some of the more unusual and esoteric areas being explored are dental holography, gene manipulation, acupuncture, laser-based optical computers, and the use of lasers to transmit power from solar-energy-gathering satellites. Future applications of the laser may only be limited by the scope of human imagination.

It doesn't take much to see that the invention of the laser is one of the most significant things to come out of the laboratory in this century. **R-E**

SERVICE CLINIC

Leakage and psychology

JACK DARR,
SERVICE EDITOR

I'M NOT TALKING ABOUT THE KIND OF leakage in which you find a small puddle under the sink (or a young puppy), but a far more troublesome kind: electrical leakage in a circuit. It is a very common kind of trouble that can cause loss of sensitivity, audio distortion, and all kinds of gremlins.

Finding leakage isn't as hard as it sounds. Make continuity checks of all components connected to the B+ and AGC lines. Most B+ lines show a pretty high resistance, at least 50K or more. If you find a point with 25K or less, stop and check out all components—especially the capacitors.

Older sets are particularly susceptible to problems with leaky capacitors. Late-model sets show fewer troubles of that sort. (I guess that eventually they learned how to build capacitors that didn't leak!) Be that as it may, don't overlook the possibility in *any* TV set.

Dry electrolytic capacitors are a common cause of problems, especially the low-voltage (25-volts) types: they have built-in leakage! If you see one on an AGC line, or in any sensitive circuit, it's a prime suspect. Sometimes I even replace capacitors that appear to be good just on general principles.

To recognize a set with low B+, look for things like resistors overheating, low AGC, and low B+.

In fact, whenever you find a resistor that looks gray or has no visible color coding, look over the circut for a leaky capacitor; you'll probably find one.

A handy tool for finding a leaky capacitor is the WCFT (the *W*ell-*C*alibrated *F*inger*T*ip). If a capacitor in the B+ is leaking, it will be warm, and that's a sure sign of trouble. They don't get warm in AGC circuits, because of the lower voltages used there; you'll have to use an ohmmeter to pin down a leaky AGC capacitor.

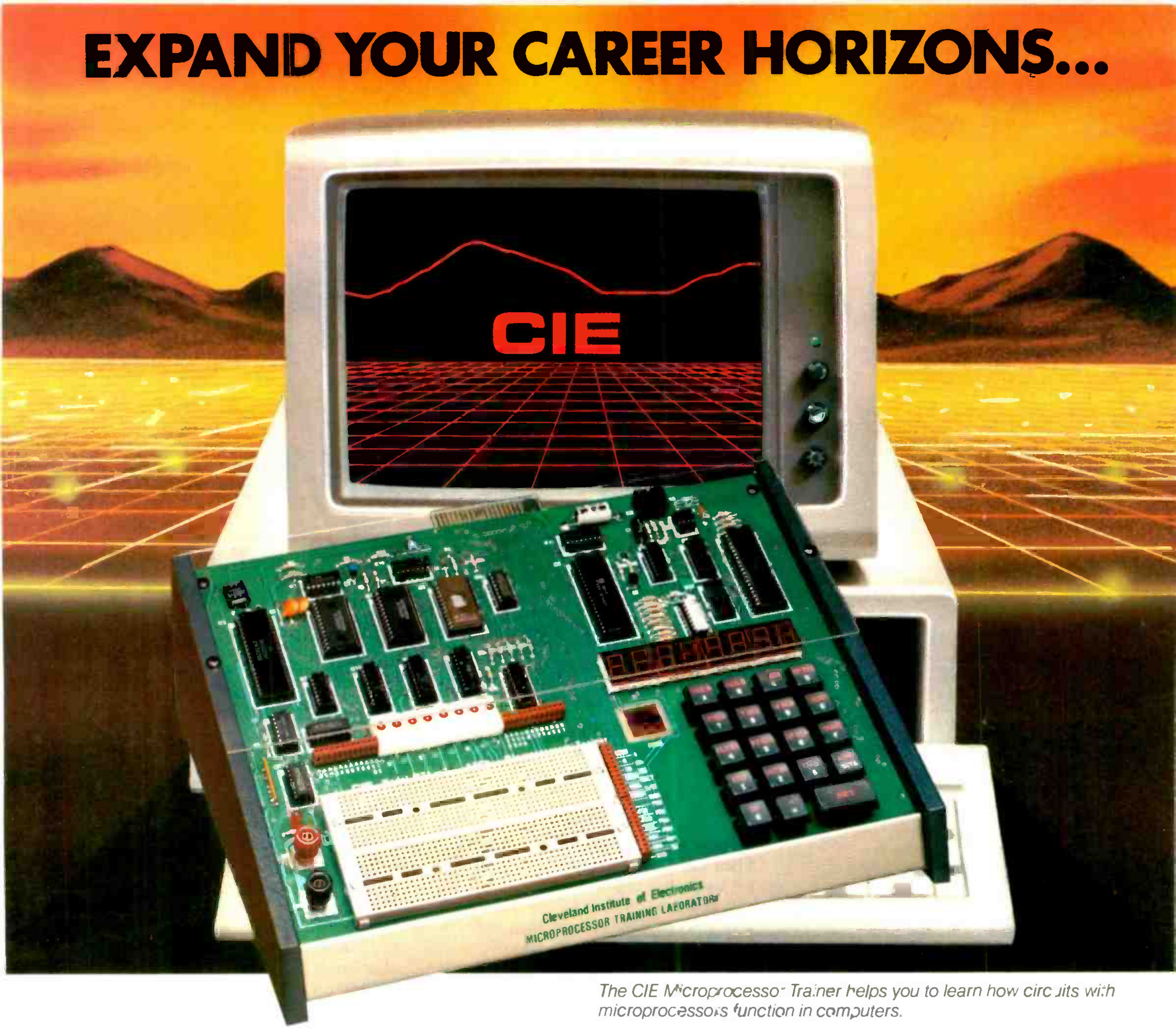
A classic example of the kind of trouble a leaky capacitor can cause is as follows. I had a set with low B+ and other symptoms. At one point in the chassis there were four or five capacitors tied to a terminal strip. The leakage was greatest at that point. So I disconnected one of the capacitors, and checked for leakage. Still there. I disconnected another capacitor; still no help. Eventually I had disconnected all the capacitors and I still had leakage! Finally I realized that the terminal strip itself was leaking through a faulty ground connection!

So the general method to use when you find excessive leakage is to start disconnecting things until the leakage disappears. Sounds awfully simple, and it is. It's time consuming, but very practical!

Serviceman's psychology

Of course there are times when, no matter what you do, you just can't figure out what's wrong with a set. Then it's time to do something different. For example, I often make it a habit to curse in German—something like "himmel herr kreuss donnertter!" It sound good, but it really only means something like "Heaven Mr. God Thunderweather!"

Then, when you've cleared the cobwebs out of your brain, you can get to work. The first step is to *think* about what's wrong and what might be causing it.



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BUILD THIS

HELIUM — NEON LASER

Build this simple helium-neon laser and start having fun with photons!

ROBERT GROSSBLATT and ROBERT IANNINI

BACK IN THE HEYDAY OF SCIENCE FICtion's era of purple prose, tales of bug-eyed monsters, death rays, and the like filled many a pulp magazine. Of course, we knew then that it was all just fantasy; you could no more have a "death ray" than you could travel faster than sound or put a man on the moon.

While those bug-eyed monsters (or BEM's, for short) have yet to pay us a visit (to the best of our knowledge), much of yesterday's science fiction is today's science fact. We even have a death ray, of sorts. Of course, we are referring to the laser, which can be a powerful weapon in the hands of those who wish to use it as such.

But the laser is also a great tool for science and industry. In just 25 years the laser has gone from far-fetched notion, to scientific reality, to common noun. Hardly a day goes by where some part of our lives is not affected by lasers. Today, the laser has joined the transistor as a hallmark of modern electronics.

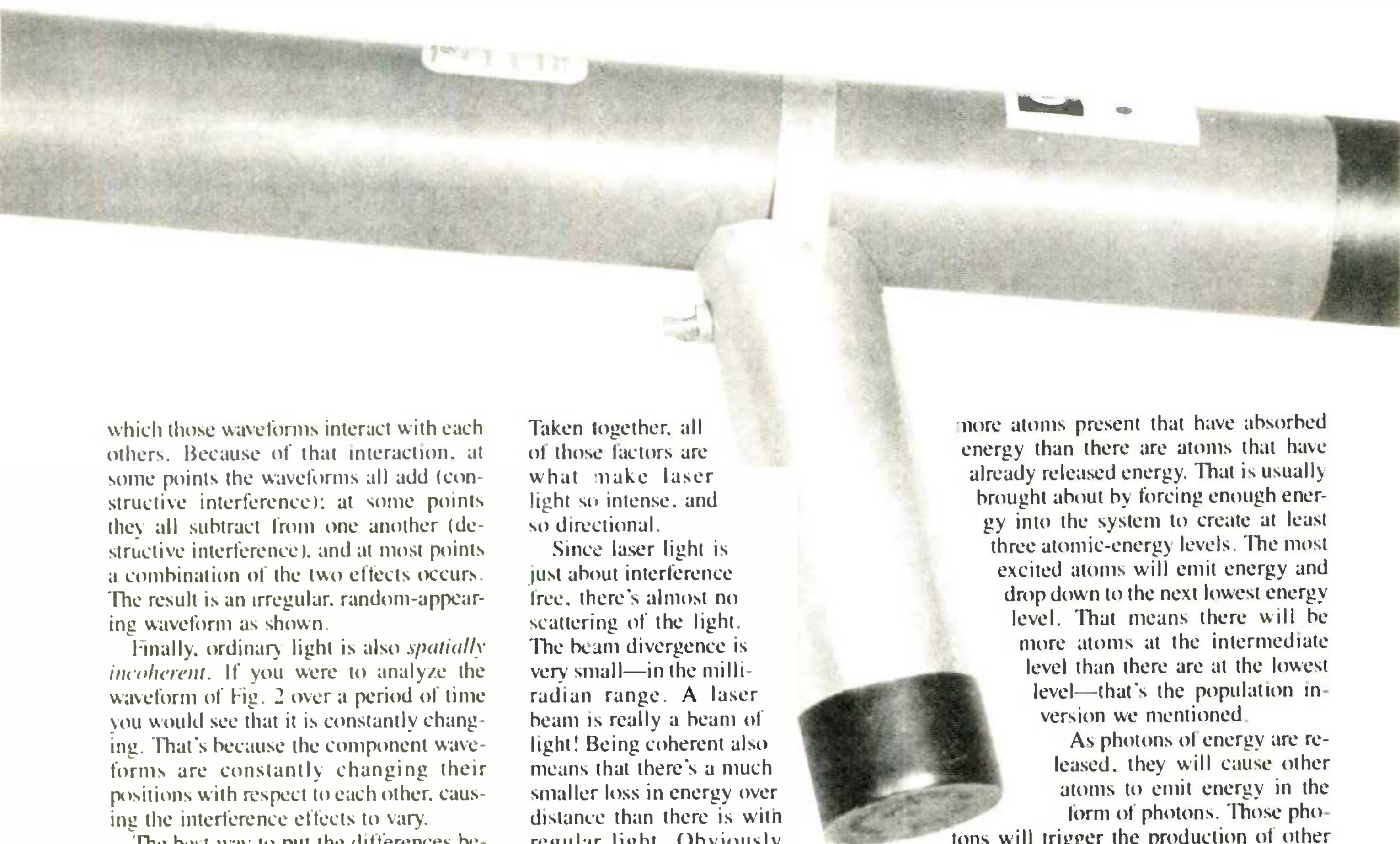
What's a laser?

The word *laser* is an acronym for *L*ight *A*mplification by *S*imulated *E*mission of *R*adiation. But for most of us, that provides a poor explanation of what a laser is and how it works. To find a better explanation, we have to leave electronics for a while, drop into the world of physics, and talk a little bit about the nature of light. You can't understand laser light until you have some familiarity with the properties of light in general.

There are three ways in which laser light differs from ordinary light, and each of those differences contributes to the special characteristics of a laser. Let's begin by looking at some of the characteristics of ordinary light.

Ordinary light has a relatively wide bandwidth. That means that a spectrographic analysis would reveal that regular light is made up of many different wavelengths. Just about everybody has seen, or done, the experiment in which a beam of white light is directed through a prism and split into different colors. The ordinary light we see as white, therefore, is actually made up of different color elements—it's *polychromatic*. Figure 1 shows the composition of visible light, and the relative sensitivity of the human eye to various wavelengths.

Ordinary light is also *temporally incoherent*. By that we mean that the various components of the light do not share any time relationship; they are all randomly out-of-phase with respect to each other. Thus, if you were able to look at the waveform of a beam of ordinary light, you would see something that looks like Fig. 2. The irregularity and random appearance of that waveform is caused by the presence of waveforms of differing frequencies in the light, and the ways in



which those waveforms interact with each others. Because of that interaction, at some points the waveforms all add (constructive interference); at some points they all subtract from one another (destructive interference), and at most points a combination of the two effects occurs. The result is an irregular, random-appearing waveform as shown.

Finally, ordinary light is also *spatially incoherent*. If you were to analyze the waveform of Fig. 2 over a period of time you would see that it is constantly changing. That's because the component waveforms are constantly changing their positions with respect to each other, causing the interference effects to vary.

The best way to put the differences between ordinary and laser light in perspective is to compare light to sound. Ordinary light, because of all the things we just talked about, can best be compared to noise. The waveforms at any moment in time are not only randomly spaced, but there's an unpredictable mix of frequencies as well.

Now, if regular light is like noise, then laser light can only be thought of as the purest sound imaginable. For openers, laser light is highly monochromatic—a spectrographic analysis would show that it is composed of light of only one wavelength. And where regular light is temporally incoherent, a laser is temporally coherent—all of the light waveforms are in phase with each other. That is one of the reasons why a laser puts ut light of such pure color. Being monochromatic helps, of course, but being temporally coherent as well means that there's almost a complete absence of what would be called distortion in a sound wave.

As you might have already guessed, laser light is also spatially coherent. If you looked at the waveforms over a period of time, there would be absolutely no shifting or movement. Considering the absence of interference effects, that is exactly what you would expect to happen. Taken together, all of those factors are what make laser light so intense, and so directional.

Since laser light is just about interference free, there's almost no scattering of the light. The beam divergence is very small—in the milliradian range. A laser beam is really a beam of light! Being coherent also means that there's a much smaller loss in energy over distance than there is with regular light. Obviously, since laser light is so different from regular light, it can't be produced the same way. And in order for us to understand how it's produced, let's see how regular light is produced.

Electromagnetic waves in general, and light in particular, is produced when an atom gives off energy. Now, an atom either takes on energy (absorption), or gives off energy (emission), by having its electrons move from one energy level to another. Once energy has been supplied to the system, and absorbed by the atom, emission can occur in one of two ways—it can happen spontaneously, or it can be stimulated.

Spontaneous emission is the result of natural atomic decay. The electrons randomly drop in energy level and produce the kind of waveforms shown in Fig. 2. When you power up a light bulb, for example, the atoms in the filament absorb energy and release it as a combination of heat and ordinary, incoherent light.

Stimulated emission is a completely different process. The idea is to keep the atoms from releasing their absorbed energy in a random manner. In order to do that, you have to create a state of affairs called a "population inversion." In simple terms, that means that there have to be more atoms present that have absorbed energy than there are atoms that have already released energy. That is usually brought about by forcing enough energy into the system to create at least three atomic-energy levels. The most excited atoms will emit energy and drop down to the next lowest energy level. That means there will be more atoms at the intermediate level than there are at the lowest level—that's the population inversion we mentioned.

As photons of energy are released, they will cause other atoms to emit energy in the form of photons. Those photons will trigger the production of other photons. And if the emission is bounced back and forth between two mirrors the production of photons will continue to build in phase and the result will be, you guessed it, a beam of laser light with a waveform that looks like that shown in Fig. 3.

Making a laser

Now, understanding the basic theory and putting it into practice are, as we all know, two completely different things. Creating the population inversion you need to produce a laser beam is really an iffy, ticklish business. Everything has to be just so or nothing will happen. The mirrors have to be of a certain type to produce the in-phase coherent energy needed for a laser. And enough energy of the right type has to be forced into the system to make the whole thing work.

The kind of energy you have to pump into the system depends on the type of material you're trying to make lase. Semiconductor and gas lasers are pumped up with electrical energy while crystalline lasers, such as those made from ruby rods or YAG (*Y*trium-*A*luminum-*G*arnet) are usually pumped up optically with xenon flash tubes or arc lamps.

The laser we're building here is a gas

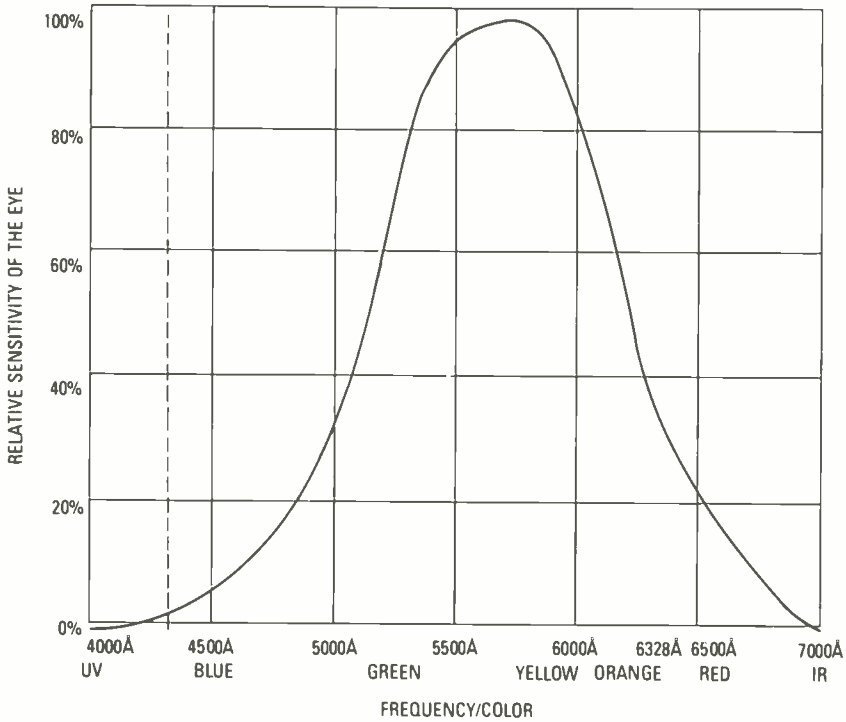


FIG. 1—THE VISIBLE SPECTRUM, and how the human eye responds to it. The wavelength of the light emitted by our helium-neon laser is 6328 Angstroms.

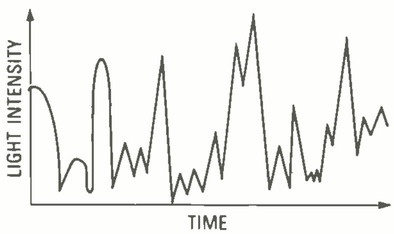


FIG. 2—THIS RANDOM-APPEARING waveform is that of ordinary light. The waveform is made up of all of the various frequencies that make up such light.

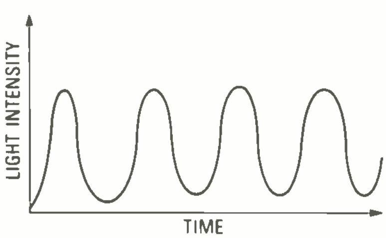


FIG. 3—LASER LIGHT is made up of light of just one frequency. It is the purest type of light possible.

laser—more specifically a helium-neon laser. The frequency of the light is 6328 Angstroms and the laser puts out about 1 milliwatt with a beam divergence of 1.3 milliradians. Now, 1 milliwatt may not sound like a lot of to you, but that's because you're still thinking in terms of regular light. Remember that the laser produces a highly directional beam of coherent, monochromatic light. The laser we're talking about here generates a beam that can be spotted on a wall more than two miles away!

Helium-neon lasers are extremely inefficient and, in order to make them work, the mechanical setup of the laser tube has to be just about perfect. It has to be properly sealed and contain the correct gas mixture. Also, the mirrors have to be perfectly aligned dielectric ones so enough reflection takes place at the proper frequency to cause the device to lase. Those mirrors must be highly reflective, within a couple of decimal places of 100%; by contrast, the silver mirrors we use every day have a reflectance factor of only 95%.

Making a helium-neon laser tube is a project that is beyond the means of most of us as it requires a fair amount of skill and equipment. Among other things, you need to have the skills and equipment required to create a precise mixture of gasses, and you need to be adept at glass blowing. All of that is not impossible, of course, but in most cases its a task that is best left to someone else; we recommend that you purchase rather than build a tube. (One source for laser tubes is mentioned in the Parts List.)

Once you have a working laser tube, actually making it produce a beam is surprisingly simple. The only electronic assembly needed is a power supply that will deliver the right voltage to make the tube fire. Figure 4 is the schematic of a power supply that can be used to trigger the laser. If it looks familiar, that's because its front end is essentially the same one used in the construction of the infrared viewer that appeared in the August 1985 issue of **Radio-Electronics**.

The power supply is a switcher with Q1, Q2, and their related components forming an oscillator that switches a squarewave through the primary windings of T1, a high voltage step-up transformer. That part of the circuit takes the battery voltage and produces about 400 volts AC at the secondary of T1. Diodes D3–D6 and capacitors C2–C5 form a voltage multiplier that takes the 400 volts from T1 and boosts it to the 1600-volts DC needed to ignite the laser tube.

The high-voltage pulse needed to ignite the tube comes from an 800-volt tap on the voltage multiplier. Resistors R3 and R4 divide that voltage to provide the 400 volts needed to charge up C9, the dump capacitor. When the SCR fires, the charge on C9 is dumped into the primary of the trigger coil, T2. Capacitor C11 charges up and, since it's in parallel with the laser tube, when the voltage builds enough to excite the gas, ignition takes place and current flows through the tube. That causes a voltage drop across R10, which turns on Q4 and turns off Q3.

As soon as the laser tube ignites, therefore, the ignition circuitry is turned off. That saves battery power because the laser tube can sustain firing at a lower voltage. The relaxation oscillator made up of Q3 and Q4, and their related components is only needed to control the firing of the SCR. Once the tube starts to lase, the voltage drop across R10 keeps the ignition circuitry turned off. If the tube stops lasing, the R9–R10 junction will drop to ground again and Q4 will turn off and unclamp Q3. The SCR will start firing again and, we hope, re-ignite the tube.

Construction

Before we actually start building the circuit, there's one very important thing you *must* keep in mind:

CAUTION! The power supply can produce as much as 10,000 volts at about 5 milliamps. That is enough juice to do a lot of damage. If you're not careful you can give yourself a severe shock. Remember that the capacitors take a while to discharge completely. You can get a real jolt even if the circuit has been turned off for five or ten minutes. Treat the circuit with respect and make sure to discharge the capacitors if you want to do some work on the circuit.

Now that that's out of the way, you can build the power supply on perfboard or use the PC board that's provided in our PC Service section, elsewhere in this magazine. If you use perfboard, remember to keep the leads as short as possible because there's a lot of high-frequency AC running around part of the circuit. Whichever method you use, make sure to keep any metal objects and your fingers away from the output section located around T2 and R11. Those are the points of the circuit where the highest voltages can be found. One short second of carelessness on your part and you're going to get zapped. If you're lucky, all it will do is hurt a lot.

The only other components in the cir-

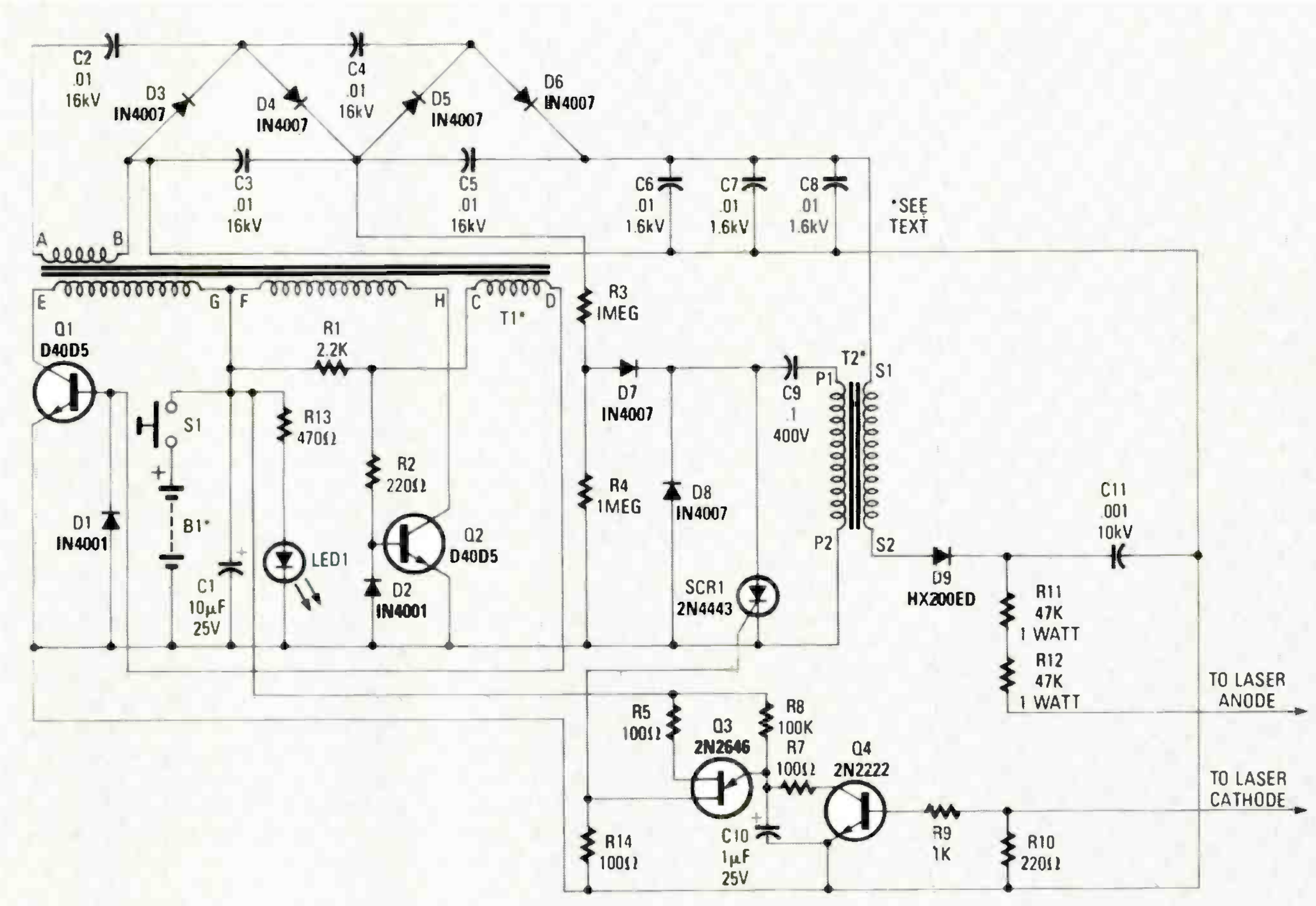


FIG. 4—THIS POWER SUPPLY is all you need to drive a laser tube like the one available from the supplier mentioned in the Parts List.

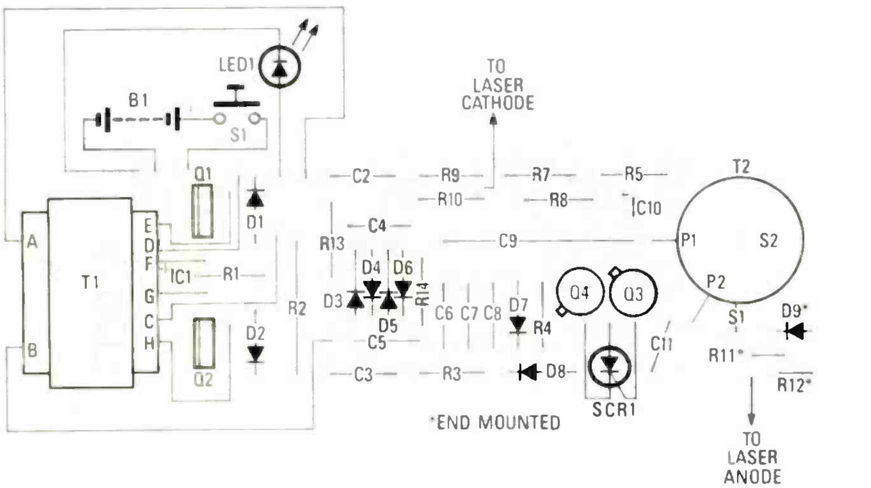


FIG. 5—IF YOU CHOOSE to use the PC board provided in our PC Service section, use this parts-placement diagram.

cuit that require special attention are the switching transistors, Q1 and Q2. The maximum current draw from the batteries is about 750 mA, so those transistors will be handling a lot of juice and getting hot. The PC-board layout shown in Fig. 5 is designed so that the transistors can be placed in such a way that their tabs can be stuck against the laminations of T1. If you are using perforated construction board, be sure that your layout allows for that, too. Use some heat-sink compound to get good thermal contact, and using small heat sinks wouldn't be a bad idea.

After you've identified the components and found their position on the board, solder them in using a minimum of solder. Once you've done that, use some high-voltage putty, paraffin, or varnish to cover the traces (or wires if you're using perf-board) that connect to all the components on the secondary side of T2 and the laser tube. That part of the circuit has the highest voltages and it's likely that arcing will take place if all the bare metal isn't covered. You may find it necessary to use the same material on the component side of the board as well.

When you finish the board, check for bridges, opens, bad solder joints, and so on. If everything seems OK, you're ready to test the power supply. Take the two leads that normally would go to the laser tube and tape them down so that they're ⅛-inch apart. Connect 10 volts to the power supply. You should see arcing across the laser-tube leads at a rate of about once a second or so; the circuit should be drawing approximately 250 mA. If the spark becomes continuous, the current draw should jump to about 750 mA—the full operating current of the laser tube. If you measure the voltage across the output of the supply, you should see an open circuit voltage of about 2500. Once the laser tube is connected, the voltage will be in the neighborhood of 1500.

If you've gotten this far without any brain damage, you're ready to connect the tube to the supply.

CAUTION! The laser tube is an expensive, delicate piece of equipment. In order to connect it to the circuit you'll be soldering leads to the metal collars at either end of the tube. Use a minimum of solder and apply heat for a minimum amount of time. Don't ever forget that the tube has a high vacuum inside and you can damage more than the tube if you destroy the integrity of

FIG. 6—A HELIUM-NEON laser tube. The cathode end can be identified by the small tube used to fill the laser tube with gas.

the seal. Use a low-power iron and a lot of common sense when you solder to the tube. Tin the wires ahead of time to keep the soldering time to a minimum.

The laser tube has an anode and a cathode end. The anode is the clear glass end of the tube and the cathode can be identified by finding the small metal tube used to fill the laser tube with gas. See Fig. 6. Once you have the ends of the laser tube identified, solder the lead from R12 to the anode, keeping that lead as short as you can. The voltage at R12 is about 1100 volts when the tube fires, so that is the point where arcing or some other type of parasitic power loss is most likely to occur. Keeping the lead as short as possible will go a long way toward eliminating any potential problems.

Connect the cathode of the tube through an ammeter to R10 and apply 10 volts to the supply. The tube should start sputtering as it tries to ignite. As you raise the voltage *slowly*, ignition will take place and the tube will fire. If you raise the supply voltage to 12 volts, you should find the tube drawing about 5 mA and the supply will be putting out about 750 mA. The operating current of the laser tube should be kept in the range of 4.5 to 5.5 mA. Less than that and the tube won't operate reliably; more than that and you'll cut down its operating lifetime. You can trim the values of R11 and R12 to get the operating current into the safe range. Just make sure you keep the total resistance of R11 and R12 at about 100,000 ohms.

The current through the tube is going to vary a lot as the battery voltage changes. If you use nickel-cadmium cells, remember that the operating voltage is going to be 1.2 in each cell for most of the lifetime of each charge. Freshly charged nickel-cadmium cells, however, can have a voltage as high as 1.5. Admittedly that doesn't last very long, but we'll mention it because adjusting the laser tube's operating current with freshly charged batteries could cause you to choose artificially high values for R11 and R12. So before you start trimming the resistors, make sure the batteries are at 1.2 volts per cell

Since the operating current is tied to the supply voltage, it's natural to think about voltage regulation. Well, there is nothing wrong with regulating the input voltage, but there are a few things to keep in mind. If you use 12 nickel-cadmium cells, you'll have a supply voltage of 14.4 and you'll be drawing as much as 750 mA from that supply. A three-terminal regulator like the 7812 would seem to be an ideal choice, but asking it to supply 750 mA is really asking a lot unless you use a 7812C, which can handle 1 amp with a good heat sink. An LM317 can be set up to put out 12 volts and it can supply 750 mA.

The biggest problem with using an IC voltage-regulator is the voltage loss that's inherent in those devices. In order to supply 12 volts, a regulator needs an input voltage of about 14.5 volts. Now that's just about the maximum you can get from the batteries. And if your particular tube wants a little bit more than 12 volts, or some of the power-supply components are a little bit lossy, you're in a lot of trouble.

So, you ask, what's the bottom line. Well, after all's said and done, unless you want to do an awful lot of circuit design, the best thing to do is let the power supply look directly at the batteries. It's not the best solution in the world, but it's probably the best thing in this situation.

The case for the laser can be as simple or as fancy as you like. Perhaps the simplest and most functional approach would be to use some lengths of standard PVC tubing. But if you do that, or completely enclose the circuit in any way, you could run into an overheating problem because of the amount of heat produced by the power supply. Because of that, it's a good idea to limit the on-time to less than a minute; keeping it under 30 seconds is even better. Further, giving the supply a 5-second or so rest between uses will increase its lifetime tremendously. Also, the better you heatsink Q1 and Q2, the better off you'll be.

Having fun

The output of the laser tube is about 1 milliwatt (or 0.4 milliwatt if the lower-powered tube offered by the supplier mentioned in the Parts List is used) and, at that power, it can't do any damage. If you had thoughts of burning your way through steel, forget it. Lasers that can do that are worlds away from the one we're building. However, that doesn't mean you can treat the light from this laser with no respect whatsoever.

CAUTION! Even a 1-milliwatt laser can be hazardous if you look directly at the beam. While we assume that anyone considering building a laser would know enough about those devices to never, never even consider doing something so foolhardy, the very nature of laser might make it very easy for accidents to happen. The beam is highly directional and very intense; to compound matters, the reflected beam is just as dangerous as the emitted beam. It's a simple matter to have the beam bounce off some shiny object and reflect back to you. You can wear safety glasses, but even if you do, be careful where and how you use the laser.

While you can use this laser, which throws an intense red beam, for such things as target spotting, perhaps its greatest use is as an introduction to the world of lasers in general. Watching the tube fire is truly fascinating and the more you experiment with it, the more you'll learn. **R-E**

PARTS LIST

All resistors ¼ watt, 10% unless noted
R1—2200 ohms
R2—220 ohms, 1 watt
R3, R4—1 megohm
R5,R7—100 ohms
R6—not used
R8—100,000 ohms
R9—1000 ohms
R10—220 ohms
R11, R12—47,000 ohms, 1 watt
R13—470 ohms

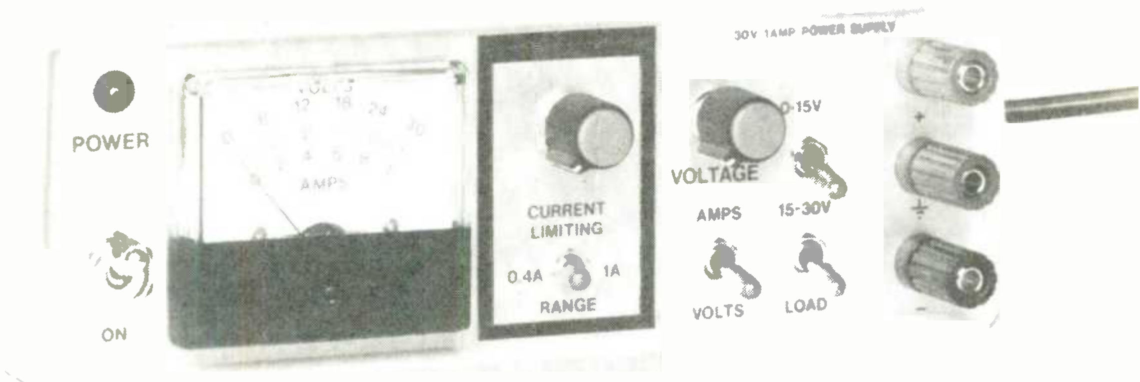
Capacitors
C1—10 µF, 25 volts, electrolytic
C2–C8—0.01 µF, 1.6 kV, ceramic disc
C9—0.1 µF, 400 volts, paper dielectric
C10—1 µF, 50 volts, electrolytic
C1—0.001 µF, 10 kV, ceramic

Semiconductors
D1, D2—1N4001
D3–D8—1N4007
D9—HX200ED, 20 kV diode
LED1—Red LED
Q1, Q2—D40D5, NPN power transistor
Q3—2N2646—UJT transistor
Q4—PN2222 NPN transistor
SCR1—2N4443 SCR

Other components
T1—12 to 400 volts, 10 kHz switching transformer
T2—10-kV trigger transformer, 400-volt primary
B1—14.4 volts, 12 nickel-cadmium cells, or equivalent
S1—SPST switch, momentary pushbutton, normally open

Miscellaneous: PC board, helium-neon laser tube, PVC tubing for case, battery holders, wire, solder, etc.

Note: The following are available from Information Unlimited, PO Box 716, Amherst, NH 03031: PC board, $4.50; switching transformer (T1), $14.50; trigger transformer (T2), $11.50; 1-milliwatt laser tube, $149.50; 0.4-milliwatt laser tube, $99.50; high-voltage diode (D9), $3.50; high-voltage capacitor (C11), $3.00.



Versatile Bench Top Power Supply

Here's a high-performance power supply to help get your designs off of the drawing board and on to a PC board!

GREG SWAIN AND FRANCO UBAUDI*

EVERYONE WHO WORKS WITH ELECtronics needs a power supply, but a commercially-produced variable-voltage current-limited power supply can take quite a chunk out of your pocketbook. So we decided to find a better way. Our power supply provides any voltage between 3 and 30 volts, at any maximum current you desire less than 1000 mA. In addition, our supply provides short-circuit protection, load switching, and switchable voltage/current metering. Further, all parts are readily obtainable and inexpensive, and the supply is easy to build and calibrate.

One feature that really sets our design apart is that it's capable of providing a full amp of power over most of its range of output voltage. Many comparable power supplies can provide one amp of current, but only over a restricted range of output voltage.

Output voltage is selected by means of a range switch with two positions: 3–15 and 15–30 volts. A potentiometer varies voltage continuously throughout the selected range. Similarly, current limiting is selected by a switch providing ranges of 150–400 and 400–1000 ma, and by a potentiometer that allows current to be varied continuously over the selected range. Actually, both current and voltage ranges overlap slightly to ensure that there are no gaps in output.

*Adapted with permission of *Electronics Australia*

The graph in Fig. 1 illustrates the high performance you can obtain from our power supply. As you can see, maximum load current (one amp) is maintained up to 27 volts, after which the load curve falls away due to transformer losses. Other specifications include load regulation that is better than 0.2% from zero to full load, and output ripple that is less than 2-mv rms.

Design considerations

Initially we considered using an LM317 three-terminal variable-voltage regulator as the basis for our supply, but we soon ran into difficulties. Despite various approaches, we were unable to come up with a cost-effective circuit that would deliver one amp over the entire voltage range. The problem was thermal limiting in the LM317 with a high input voltage and a low output voltage. Another drawback was that an additional op amp was required to provide current sensing for the current-limiting circuitry, and that would have increased both cost and complexity of the circuit.

So we rejected the LM317 and adopted the LM723. It requires a current-boosting transistor, but it has built-in current limiting. The guts of the 723 are shown in Fig. 2. It consists of a series-pass transistor, an error amplifier and a voltage reference. The error amplifier compares a portion of the output voltage with the internal reference voltage and continually regulates the base current that is applied to the series-pass transistor. That's what provides regulated output.

The 723's built-in series-pass transistor can deliver a maximum of 150 mA of current, so, in order to obtain more current, an external power transistor is required.

One particularly useful characteristic of the 723 is its built-in current-limiting circuitry. When output current reaches a preset value, the current-limit transistor turns on and that reduces the base drive to the series-pass transistor. The output voltage is thereby reduced.

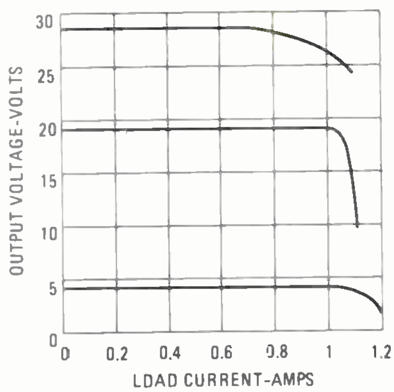


FIG. 1—POWER SUPPLY CAN SUPPLY ONE amp of current all the way to 27 volts, where output drops to about 0.75 amp.

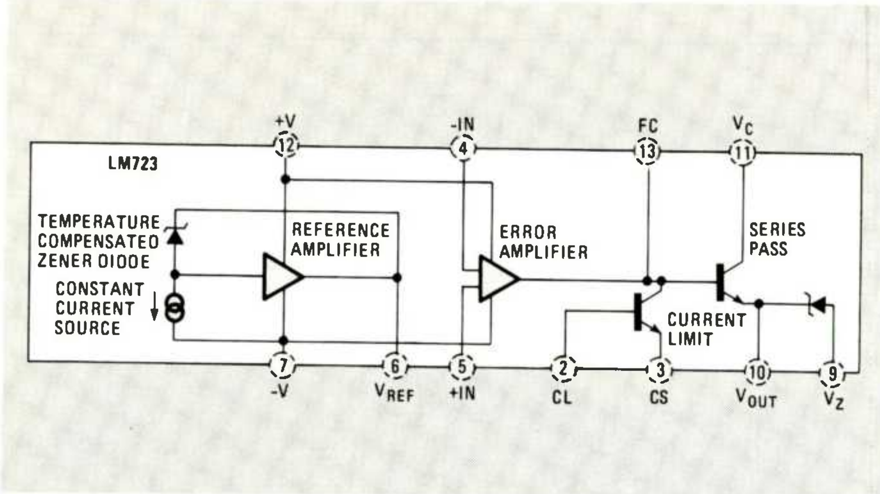


FIG. 2—THE LM723 REGULATOR has most of the circuitry necessary for a complete current-limited power supply built right in.

Circuit details

The schematic of the complete power supply is shown in Fig. 3. A tapped transformer drives a diode bridge (D1–D4) and two 2500-μF filter capacitors (C1 and C2). That provides a no-load voltage of 37 or 47 volts, depending upon the position of switch S2-a. The unregulated DC is then fed to a pre-regulator stage composed of Q1 and D5. Those components protect IC1 (the 723) from an over-voltage condition; the 723 can't handle more than 40 volts.

The LED (LED1) and its 2.2K current-limiting resistor (R1) provide on/off indication. The current through the LED varies slightly according to the transformer tap selected, but that's of no real consequence.

The series-pass transistor in IC1 drives voltage-follower Q2, which provides current amplification. That transistor can handle lots of power. It has a maximum collector current of 15 amps and a maximum V_{CE} of 70V, both of which are more than adequate for our supply.

Heat dissipation could have been a problem when drawing high current at low voltage. We solved that problem by switching the secondary winding of the transformer. For outputs greater than 15 volts, S2-a selects the 30-volt tap on the transformer, and for outputs less than 15 volts, S2-a selects the 24-volt tap.

Voltage regulation

Now let's examine in detail how the voltage-regulator section works. The error amplifier in the 723 is connected as a non-inverting amplifier with variable gain. The input to that amplifier is fixed at about 2.8 volts by R3 and R4, which are fed by the 723's internal reference voltage. Capacitor C3 is included to reduce output noise.

On the 0–15V range, switch S2-b is closed, so feedback resistance—the resistance between the output of the supply and the inverting input of the error amplifier—can be varied between 100 and 5000 ohms. That corresponds to an amplifier gain ranging from 1.1 to 6.1, and that corresponds to an output voltage ranging from 3.1 to 17.1 volts. With switch S2-b open, the gain of the amplifier is adjustable from 5.8 to 10.8, and that corresponds to an output voltage ranging from 16.2 to 30.2 volts.

The current-limiting circuit depends on the position of S3. That switch causes load current from the emitter of Q2 to flow through either R14 or R15. The resulting voltage is applied to a voltage divider network composed of R12 and R13. The voltage developed at the junction of those two resistors depends on the setting of front-panel control R13, CURRENT LIMIT. That voltage is then applied to the current-limiting transistor in the 723.

In the interests of economy, we elected to use a single meter and to switch between measuring voltage and current. It would be nice to have a separate meter for each, but cost is prohibitive. Meters are expensive, and a larger case, which is also more expensive, would be necessary to provide the necessary front panel area.

Our metering circuit is straightforward. When measuring voltage, the parallel combination of a R16 and R17 provides an effective resistance of 30K. That resistance is in series with the one-mA moving-coil meter, so it can measure a maximum of 30 volts full scale. When measuring current, the meter is shunted by the 0.5 ohm resistance provided by the parallel combination of R5 and R6. Trimmer potentiometer R7 is used to adjust the meter for accurate readings.

There's not much else to the circuit. Capacitor C6 prevents switching transients from being delivered to the output, and D6 protects the power supply from an accidentally-applied reverse voltage—from a charged capacitor, for example. Capacitor C5 ensures stability of the supply under all conditions.

Construction

Except for the front-panel switches, potentiometers, etc., and the power transformer, all components are mounted on a PC board that measures about 4⅛ × 4⅜ (inches). A foil pattern for the board is shown in "PC Service."

No special procedure need be followed when assembling the PC board, although the job will be much easier if the lower-profile components are installed first. Refer to the parts-layout in Fig. 4 to install all components; be careful to install IC1, the diodes, the transistors, and the elec-

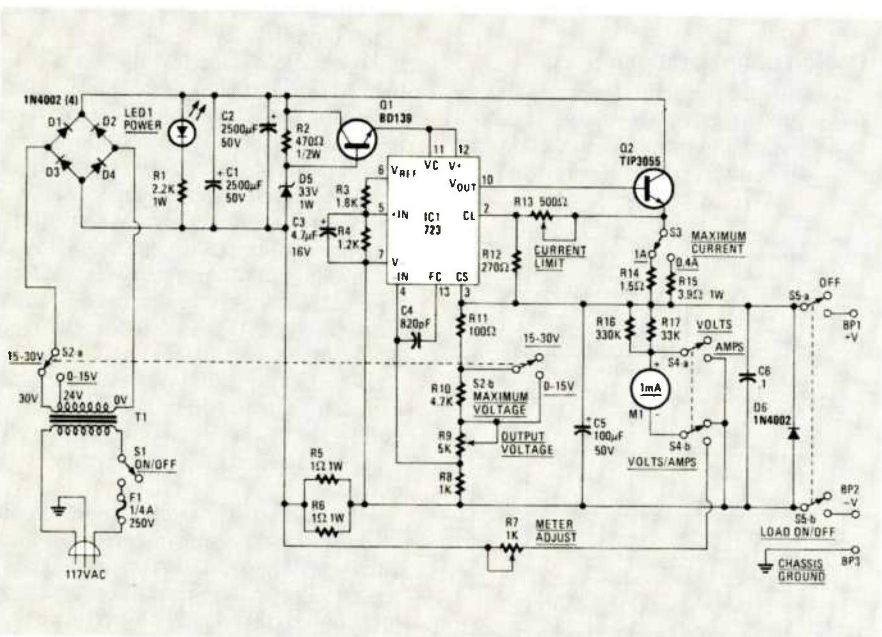


FIG. 3—SCHEMATIC DIAGRAM OF OUR POWER SUPPLY shows how the LM723 can be put to good use with little more than a current-amplifying transistor (Q2).

trolytic capacitors in the correct orientation. Also, mount transistors Q1 and Q2 without trimming their legs: the full length will be necessary if you use the heat sink arrangement shown in Fig. 5.

The power supply is housed in an attractive plastic instrument case that measures about 7⅞ × 6⅛ × 2¾ (inches). If you purchase the kit from the source mentioned in the parts list, you'll receive special front and rear panels.

The layout of the front panel is shown in

PARTS LIST

All resistors ¼-watt, 5% unless otherwise noted.

R1—2200 ohms, ½ watt
R2—470 ohms, ½ watt
R3—1800 ohms
R4—1200 ohms
R5, R6—1 ohms, 1 watt
R7—1000 ohms, trimmer potentiometer
R8—1000 ohms
R9—5000 ohms, panel-mount potentiometer
R10—4700 ohms
R11—100 ohms
R12—270 ohms
R13—500 ohms, panel-mount potentiometer
R14—1.5 ohms, 5 watts
R15—3.9 ohms, 1 watt
R16—330,000 ohms
R17—33,000 ohms

Capacitors

C1, C2—2500 µF, 50 volts, electrolytic
C3—4.7 µF, 16 volts, electrolytic
C4—820 pf, ceramic disc
C5—100 µF, 50 volts, electrolytic
C6—0.1 µF, ceramic disc

Semiconductors

IC1—LM723 voltage regulator
D1–D4, D6—1N4002 rectifier
D5—1N5257B, 33 volts, 1 watt, Zener diode
Q1—BD139 or ECG373
Q2—TIP3055

Other components

F1—¼-amp, 250-volt fuse
M1—0–1 mA panel meter
S1—SPST power switch
S2, S4—DPDT switch
S3—SPDT
S5—DPST
T1—117 VAC primary, 0–24–30 volt secondary, 1 amp (Altronic A6672)

Miscellaneous

Line cord, heatsink, mica insulators, silicone grease, PC board, case, binding posts, knobs, solder, wire, etc.

Note: A complete kit of parts, including case, is available for $49.95 from Imtronics Industries, Ltd., 11930 31st Court, St. Petersburg, FL 33702. Florida residents must add appropriate sales tax.

Fig. 6. Note that, if you use a different meter than the one specified in the Parts List, you'll have to alter the drilling dimensions accordingly. The kit includes *Scotchcal* artwork that you can affix to the front panel and then spray with a hard-

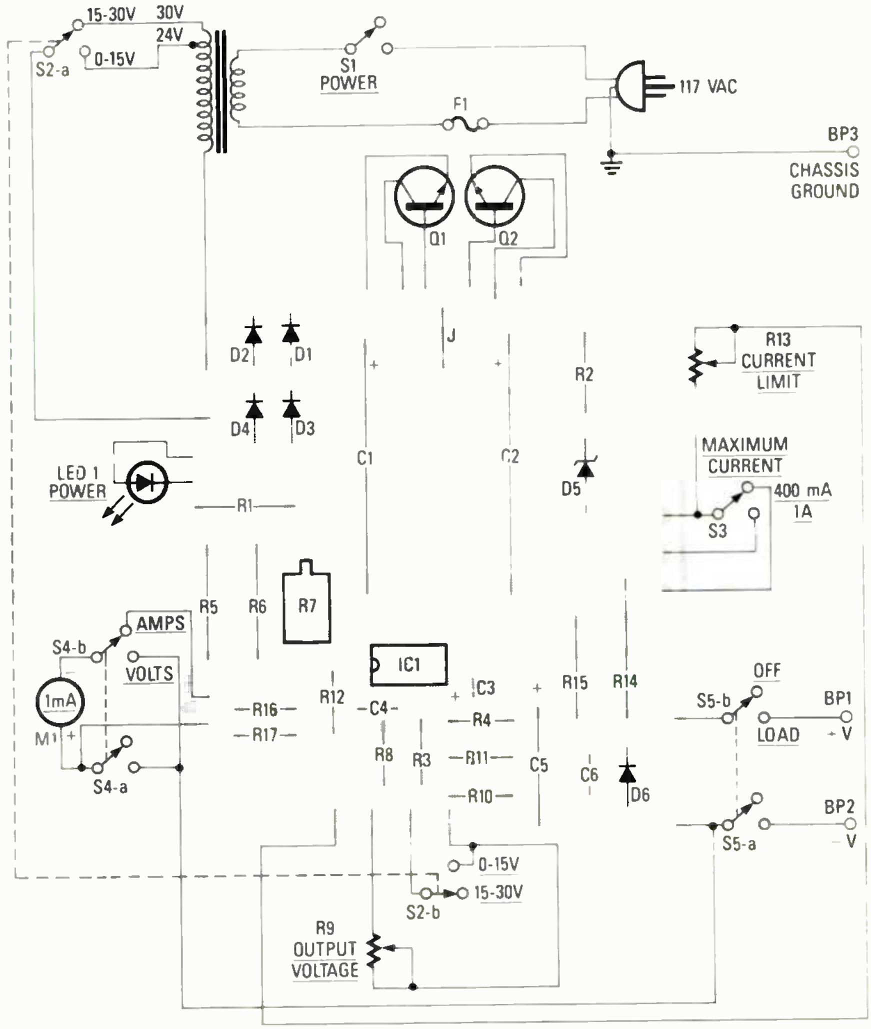


FIG. 4—ON- AND OFF-BOARD COMPONENTS are mounted and wired as shown here.

setting clear lacquer to protect the artwork, which can then be used as a template.

You'll also have to drill holes in the rear panel for the fuse holder, the power cord, and the heatsink. But, don't drill the heatsink holes yet.

Secure the PC board to four internal mounting posts using self-tapping screws, and bolt the power transformer to the case using machine screws and nuts. Include a solder lug under the nut nearest the rear panel.

Use medium-duty hookup wire (16 gauge) for all wiring that carries the full supply current, and light-duty hookup wire for the potentiometer, the meter, and the LED.

Install the rear panel and then mark the positions of the holes for the power transistors. Drill those holes, and then you can use the rear panel as a template for drilling the heatsink mounting holes. The heatsink may have to be trimmed to fit the rear panel. Both transistors must be insulated from the rear panel using mica washers and insulating bushings. Smear heatsink grease on all mating surfaces, including the rear of the heatsink, and then bolt the assembly together using machine screws and nuts as shown in Fig. 7. Finally, use an ohmmeter to make sure that there is no conductivity between the metal tabs of the transistors, and the rear panel, or the heatsink.

Anchor the 117 VAC power cable to the rear panel with a cable clamp. Solder the "hot" 117 VAC lead to the fuseholder, the neutral wire to the power transformer, and the ground-wire to the solder lug beneath the transformer. In addition, separate ground leads should be run to both the rear and the front panels.

We recommend that you use heat-shrink tubing over all 117 VAC connections to the fuseholder, the transformer, and the power switch. That will prevent you from being shocked while doing the testing and calibration discussed below. Use wire with thick insulation for the 117 VAC circuit, and do not use a miniature metallic switch for POWER switch S1.

Shown in Fig. 8 is a meter scale you can use to replace the scale that comes with the meter. Being careful not to bend the meter's needle, gently pry the plastic

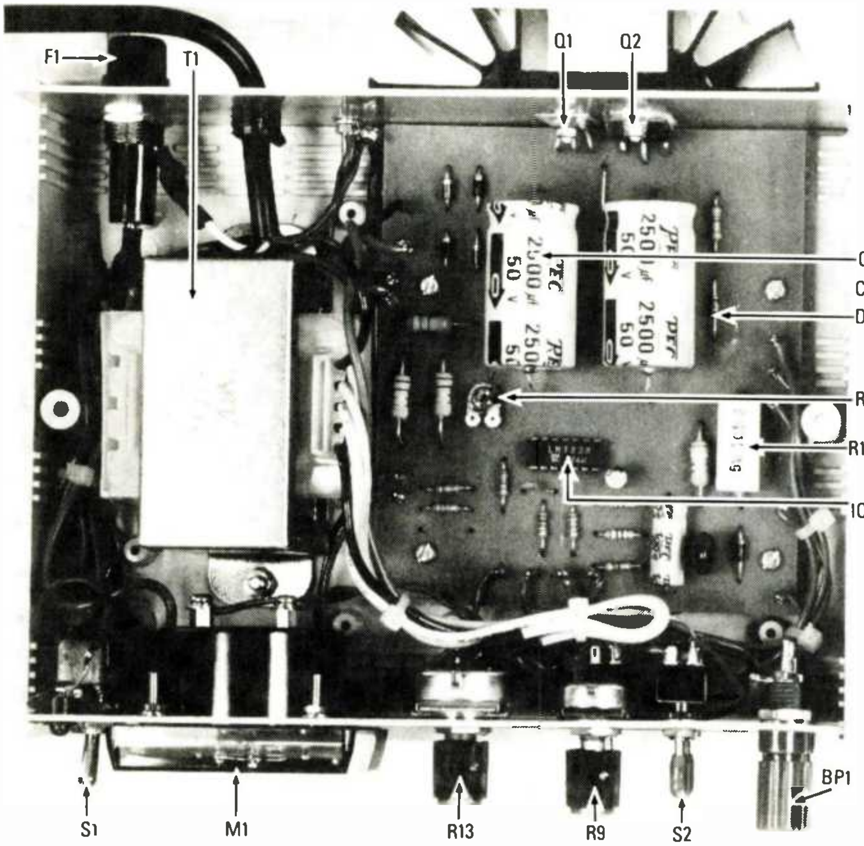


FIG. 5—**INTERNAL VIEW OF THE POWER SUPPLY** reveals its neat, clean, design.

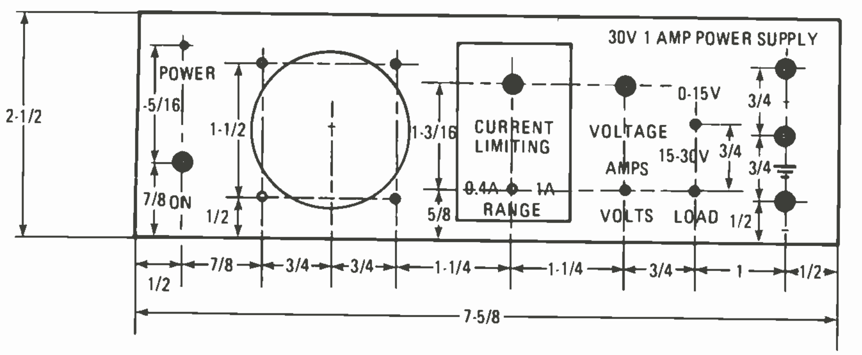


FIG. 6—**DRILL THE FRONT PANEL OF THE POWER SUPPLY** according to the dimensions shown here.

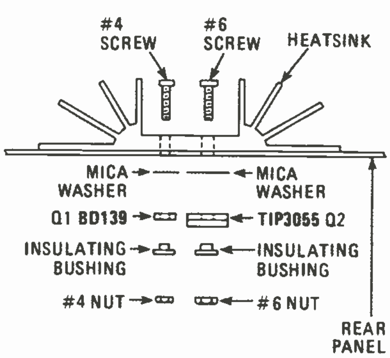


FIG. 7—**ATTACH Q1 AND Q2 to the rear panel and the heatsink as shown here. Use heatsink grease on all mating surfaces.**

cover off the meter and glue an enlarged copy of our scale over the present one.

Testing and calibration

Connect a voltmeter across the output binding posts, turn the supply on and close the LOAD switch. If all is well, the POWER LED will light up and you will be able to vary the output voltage from three to 30 volts using the RANGE switch and the OUTPUT VOLTAGE control.

Verify that the voltage reading on the supply's meter and on your meter are identical. Note that we left room on the PC board for an additional trimmer resistor that, if used, would parallel R16 and R17. You can install an additional high-

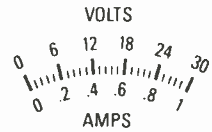


FIG. 8—ENLARGE OR REDUCE THIS METER SCALE to fit the meter you use, and then glue our scale over yours.

valued resistor there to increase the accuracy of the voltage displayed by the meter, if necessary. Just use Ohm's law to calculate the appropriate value.

Assuming all is well, open the load switch, select the 0–15 volt range, and then turn the OUTPUT-VOLTAGE potentiometer fully counter-clockwise. Now set the CURRENT-LIMIT control to the middle of its rotational range, the CURRENT-LIMIT switch to the one amp range, and the VOLTS/AMPS switch to amps. Now connect a one-amp ammeter directly across the output binding posts and close the load switch.

Your meter should indicate a current of about half an amp, although the supply's meter may show something different now. Adjust the CURRENT-LIMIT control so that the multimeter reads 1A, and then adjust trimmer resistor R7 so that the supply's meter reads the same.

Finally, vary the CURRENT-LIMIT control and verify that the meter reading corresponds closely to that on the multimeter throughout its range.

Applications

Why is adjustable current limiting useful? First, it protects the power supply in case its output is inadvertently short-circuited by improper circuitry. Second, it helps prevent that circuitry from being damaged by excessive current due to a fault condition.

Why is a separate LOAD switch useful? It allows you to remove load voltage without turning the supply off. The latter can cause switching transients that might damage the power supply, the circuit under test, or both.

So, when testing out an untried circuit, turn the LOAD switch off, and the voltage and current controls all the way down. Connect the supply to your circuit, turn the LOAD switch on, and gradually increase output voltage to the required voltage. Next set the meter to measure current and turn the CURRENT LIMIT control up *slowly* while monitoring the meter. If the needle of the meter seems to jump at all throw the LOAD switch quickly. But if the needle moves smoothly as you rotate the control, most likely the circuit has no severe power-related problems. In other words, you're not likely to fry anything! So now you're ready to start the real work—testing and troubleshooting your circuit. But that's another article. **R-E**

Electronic Aids for the Blind

While electronic aids can't restore sight to the sightless, they can help reduce some of the hardships of being blind.

RAYMOND M. FISH, Ph.D, M.D.

IN 1751, BENJAMIN FRANKLIN SUGGESTED that sight could be restored through the use of some form of electrical stimulation. That has, at least thus far, not proven to be possible. We have, however, devised many useful electronic aids for the blind in the 200-plus years that have passed. In this article, we will examine some of those aids, and see how electronics can be used to minimize some of the disability that accompanies blindness.

Aides for the blind can generally be divided into two general categories, reading aides and mobility aides. Reading aides allow persons with limited or no vision to gain access to printed information. Mobility aides permit the visually handicapped to move about in an unfamiliar environment.

Reading aides

Persons with very poor vision (but who are not completely blind) can be helped by devices that magnify print. Some such devices are purely optical, while others use television cameras or computers to achieve their objective.

There are also many devices that allow a totally blind individual access to the printed word. Those are often scanning devices that produce an audio or other signal in response to the printed material that is input to them.

Not all scanning devices are recent innovations. The Optophone, for instance, was invented in 1913. The device, and later models of it, have up to 9 light sensitive detectors arranged in a vertical column. The array of detectors is manually scanned across a printed line. Each detector activates (or deactivates) a tone of a certain frequency. The higher up in the column the detector is located, the higher the frequency of the tone that it controls. As the array of detectors is moved across printed material, time varying chords or tones are produced. With practice, the user can use those tones to "read" the material. "Reading speeds" of up to 60 words per minute have been achieved with the Optophone.

There are, of course, many similar devices. The Lexiphone is a reading aide that recognizes letters and emits a different sound for each. Other devices pronounce the actual letters. No doubt future devices will automatically scan a page, recognize and pronounce many words, and spell the others.

Some devices replace the audio signal with tactile simulation (stimulation of different regions of the skin). In the Visotactor, eight photocell signals activate eight tactile stimulators. There are two stimulators on each of four fingertips. Other tactile devices have two dimensional arrays of over 100 photodetectors. Each detector causes vibration of a pin in a corresponding array of tactile stimulators on a finger. One such aide, the Optacon, allows users to "read" printed and typewritten material as well as characters on a computer monitor.

A variety of different devices have been developed that permit the visually handicapped to "read" the output of a computer. It is relatively easy to make an LED or television monitor with large print for persons who have limited vision. For the totally blind, commercially available computer terminals with speech synthesizers can speak at rate of several hundred words per minute.

Mobility aides

The purpose of a mobility aide is to allow a blind individual to move reasonably rapidly in an unfamiliar environment.

Development of the laser cane began in the 1950's. Those devices, which are now commercially available, emit pulses of infrared light that are reflected from obstacles. With the laser cane, distance is inferred by optical triangulation. In one version of the cane, lasers emit 0.1-microsecond pulses of light 40 times a second. Light reflected from objects is detected by a photodiode, which is mounted behind a lens. The angle made by the reflected ray passing through the receiving lens is a function of the distance to the object. Three beams are emitted. One downward, one straight ahead, and one upward. The downward beam warns of stairs and curbs by means of a low-pitched tone. The beam that is emitted straight ahead warns of obstacles by stimulating the index finger of the hand holding the cane. The upward beam detects obstacles at head height and warns of them by means of a high pitched tone. Information about objects to either side is obtained by twisting the wrist in a rhythmic fashion while walking.

The Kay Ultrasonic Spectacles radiate ultrasonic signals that are reflected by obstacles. One receiver for each ear transforms the reflected energy into audible sounds. Left-right direction is coded primarily by the relative intensity of the signals in the two ears. For instance, the sound will seem to come from the left if the sound is louder in the left ear, and from the far left if a lot louder in the left ear; the same holds true, of course, for sounds heard in the right ear. A sound will seem to come from straight ahead if it is heard equally in both ears.

The Kay Spectacles code distance by changing the frequency of the sound. The reflective properties of the obstacle effect the amplitude and pattern of the sound heard. Loudness increases as the distance to an obstacle is reduced. The elevation of an object can be determined by moving the head up and down (the maximum sound indicates the height).

The output of the Kay Spectacles is coupled to the ears through small plastic tubes that do not touch the ears; it is important to not interfere with normal hearing, which is in itself important for safe travel.

Tactile mobility aides present pictures of a person's surroundings by stimulating the skin mechanically or electrically. One such unit is the Mowat sensor. That device emits a tight beam of ultrasonic signals. When the signals strike an object, they are reflected back to the unit, which vibrates in response. Proximity to an object is indicated by the rate of vibration. Using that device, it is possible to detect large objects in the user's path, or conversely, openings, such as doorways and windows, in a wall, etc.

It is also possible to use the output of a TV camera to convey information to a blind individual. Information from the camera can be presented in either tactile or audible from. In a tactile system, an array of several hundred mechanical vibrators or electrical stimulators, applied to the forehead, back, or other part of the body, is used. The vibrations or electrical stimulation given at each point in the array corresponds to the image detected by a television camera. With a few hours of training, such a system can allow a person to recognize several dozen different objects and move about in simple environments.

Similar results can be obtained by coding the image detected by a television camera by sound. A television image is scanned in raster fashion over a period of about 10 seconds. The intensity of light at every point in the picture determines the loudness of the sound the person hears. The left-right and vertical positions of the sound are presented to the person by means of stereo headphones. A block diagram of one such system is shown in Fig. 1. As the scan moves from left to right, the loudness in the right ear becomes greater than that in the left. The vertical position of the scan is coded by sound frequency—high locations are coded by high frequencies, lower positions by lower frequencies. That coding scheme permits persons with a few hours of training to recognize a limited number of real objects and to walk about in a simple environment.

Figure 2 shows the audio signal presented to each ear as the scan moves from left to right. The top waveform is that present at point C in the block diagram of Fig. 1; the bottom waveform is at point D in Fig. 1. When the scan is at the left, the sound is mostly presented to the left ear. In the center, the sound intensity is equal in the two ears. At the right the sound is loudest in the right ear. Sound intensity varies exponentially with left-right position. Varying the sound intensities linearly with position can be done, but the sound will not seem to the listener to move with a constant speed from left to right during the scan.

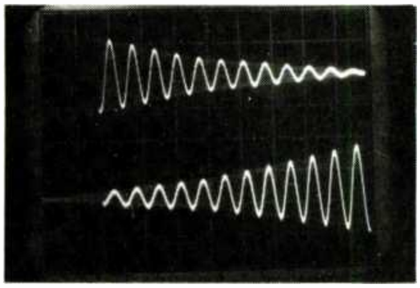


FIG. 2—AUDIO OUTPUT versus horizontal position. The top waveform in this photograph is the audio signal fed to the left ear as the scan moves from left to right. The bottom waveform is fed to the right ear.

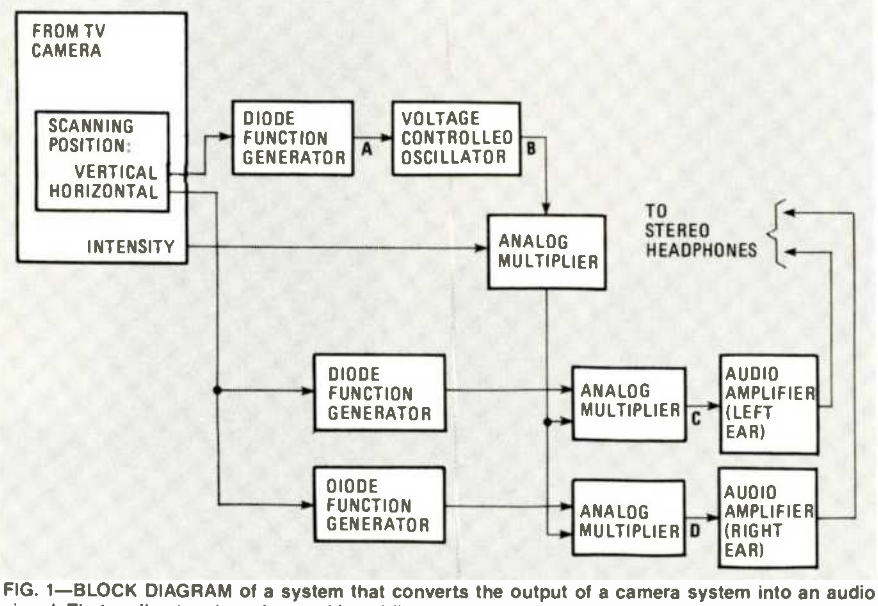


FIG. 1—BLOCK DIAGRAM of a system that converts the output of a camera system into an audio signal. That audio signal can be used by a blind person to locate various objects and obstacles.

The top waveform in Fig. 3 shows the audio signal generated with vertical position. Higher frequencies are associated with higher positions in the image. That signal, is output by the VCO in response to an exponential input signal (the bottom waveform in Fig. 3) that is generated by the diode function generator. In the block diagram, the top waveform in Fig. 3 is found at point B, while the bottom waveform is found at point A.

Figure 4 shows the *D*iode *F*unction Generator. The DFG produces an output voltage that varies approximately exponentially. While the input signal to the DFG (the raster scan voltage) increases linearly, the output will increase with several changes in slope, as shown in the bottom waveform of Fig. 3. (There is also a polarity change because of the inverting operation of the amplifier, but here we are discussing only increases in magnitude). Signals under about 2 volts are passed linearly to the operational amplifier. When the input voltage gets above 2 volts, the diode controlling SLOPE 2 turns on, passing even more current to the summing junction (inverting input) of the operational amplifier. The current through the diode divides, part going to ground through R7, and the rest going to virtual ground through R5. The voltage that must occur on the input to cause the diode to conduct is determined by the values R21 and R22. The increase in slope obtained in the output voltage depends on the values of the R5 and R7. As the input voltage increases, additional changes in slope are made by the other diode resistor networks.

Unfortunately, such systems can not present a detailed picture of an area to a blind individual. The tactile and auditory systems can only present information about several hundred points in a few seconds. Most real environments contain images that need to be coded with hundreds of thousands of points if complete information is to be conveyed. A reconstruction of an image with even 10,000 points (100 on a side) will look blurred. An image made up of 400 points (about the capacity of most systems) is hopelessly blurred. Examine some newspaper images closely, seeing how many dots are needed to reproduce various types of images. It will become clear that the above systems cannot code clear images of a real environment.

Thus, to determine such things as the presence of small obstacles or irregularities in the ground, it is still best to rely on a cane. The tactile and auditory systems can be useful, however, for such things as sensing distance to any obstacles, and to the ground. That information would be presented to the blind person in the form of auditory or tactile stimulation; the stronger the stimulation, the nearer the object. In addition, such systems give

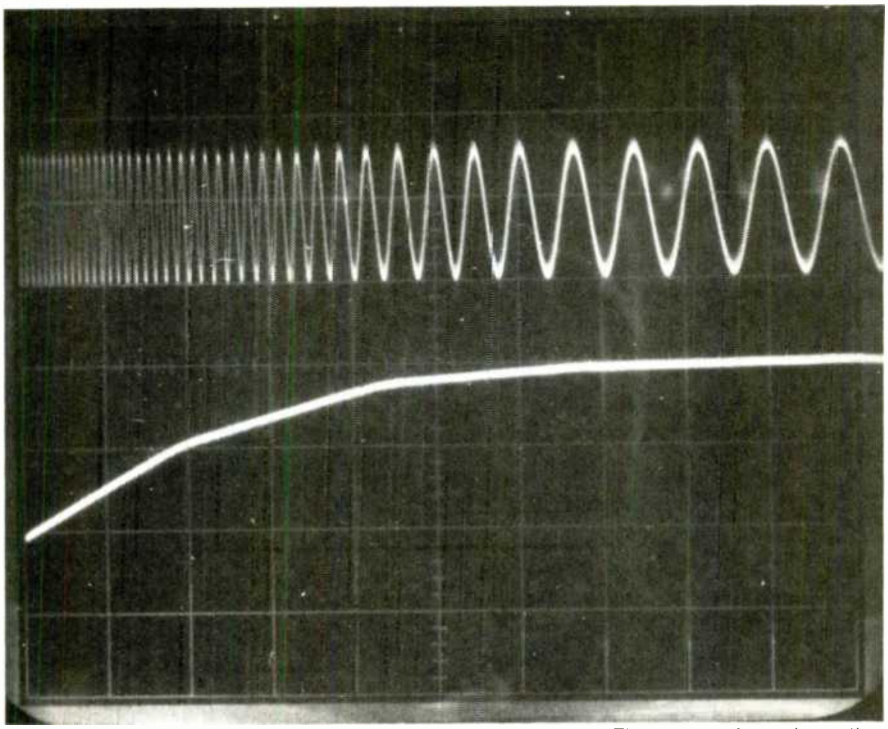


FIG. 3—HEIGHT INFORMATION is coded by changes in frequency. The top waveform shows the frequency change as the scan moves from top to bottom. That waveform is generated in response to the signal shown in the bottom of the photograph.

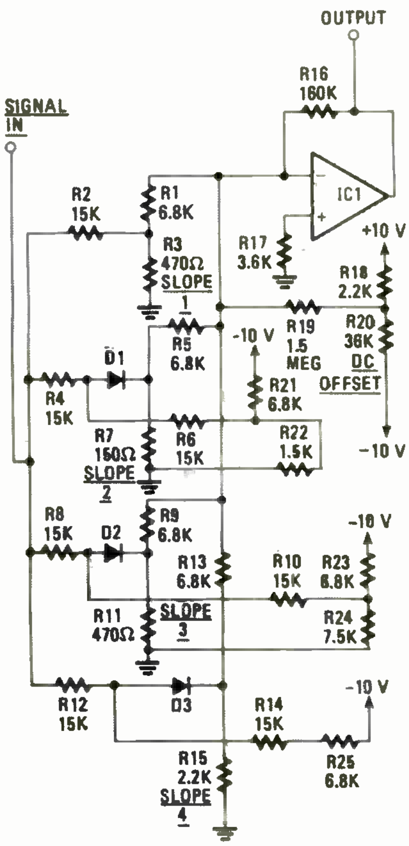


FIG. 4—SCHEMATIC DIAGRAM of the diode function generators used in the scanning system of Fig. 1.

a more three-dimensional picture of the environment by giving the up-down, left-right positioning of objects. In audio systems, that position is coded as discussed above. In tactile systems, the location of the object is coded by the position of the tactile stimulator.

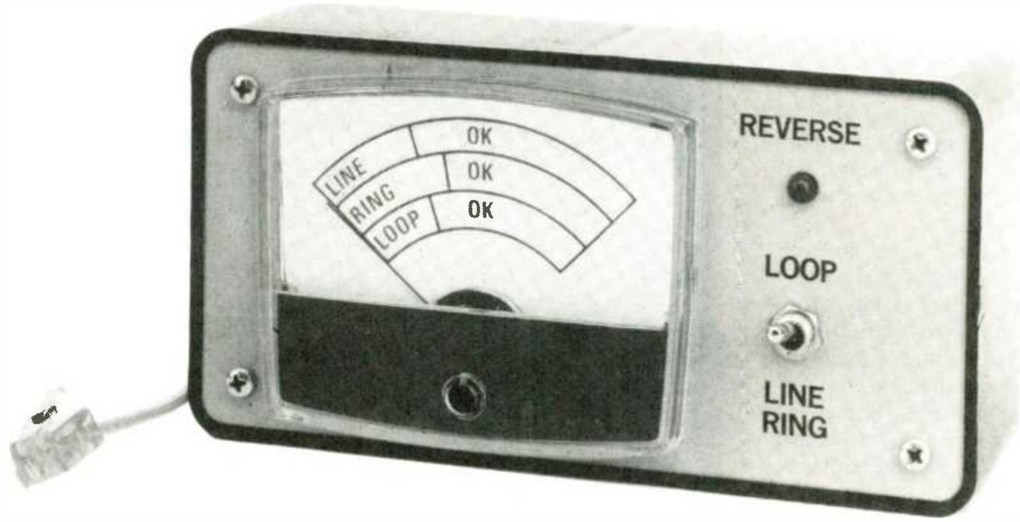
Direct stimulation of the brain

As we stated at the start, Benjamin Franklin suggested that sight could be restored to the blind through electrical stimulation. Experiments to do just that have, in fact, been performed, but with very, very limited success. At best, a blind person has been able to discern several dozen spots of light when electrodes implanted in the brain were stimulated.

When one examines the nature of sight, and the structure and function of the brain, the reasons for the poor results become apparent. For one thing, for adequate sight, it is necessary to transmit an image to the brain that consists of over 10,000 individual points. In addition, the image must be updated at least once a second.

The major limitation is on the number of points of light that can be communicated to the brain. Thus far, the effective minimum spacing for electrodes is about 2 millimeters. By comparison, the optic nerve is only about 2 millimeters in diameter, and the entire visual cortex of the brain (the region of the brain that "processes" the signals that come from the eyes) is only several centimeters in size. Because of that, the maximum number of electrodes that can be used is limited to a very few.

Therefore, providing real vision for the blind seems to be an impossible dream, or a challenge for doctors and engineers looking for a new frontier. **R-E**



Telephone Line Tester

HERB FRIEDMAN

Beat the telephone service guessing game with this simple yet effective telephone-line tester.

EVER SINCE THE BREAKUP OF AT&T, THE odds of getting a telephone circuit repaired on the first attempt are only 50-50. The problem is that now the telephone lines are the responsibility of your local telephone company, while the receiver itself is the responsibility of its supplier, most often AT&T. If you contact the supplier, and the problem is not in the telephone, they won't help you. Similarly, if you call the local telephone company, and the problem is in the telephone, you are also out of luck. But this time there's a kicker—you can be billed $50.00 or more for a "service" call. And you still won't have a working phone.

One of the ways to avoid playing the telephone-service guessing game, and thus any unnecessary and unconscionable service charges, is to first, conduct your own line tests, using the telephone-line tester shown in Fig. 1. If the telephone line passes its tests, any problems must be the fault of the receiver itself. If the line doesn't pass its tests, you can call in the local telephone company secure in the knowledge they won't—or can't—stick you for a service charge.

The telephone-line tester is intended for the commonly used modular connector system. To use the device you simply unplug the telephone from its modular connector and substitute the tester's connector. It for some reason you want both the tester and telephone to be simultaneously connected, you can use a Y-adapter at the modular jack. If the telephone uses the older 4-pin "block" connector, you can use a modular-to-4 pin block adapter; those are available in both single and Y versions.

What it tests

The telephone-line tester checks the operating parameters of the telephone company's wiring at the modular connector. That includes the open circuit or "on-hook" line voltage; the "loop" voltage, which is the line voltage when the telephone is off hook (when the handset is lifted from its cradle); the ringer voltage, and the polarity of the line. The telephone line's voltage conditions are indicated by a meter, and the polarity of the line connections is indicated by an LED.

Normally, polarity is not a problem because most standard telephones will work regardless of the polarity of the DC voltage on the telephone line. (The purchase of any telephone that is polarity sensitive should be seriously questioned.) However, reversed line polarity can interfere with certain kinds of switching equipment, in particular, some of the low-cost conference and multi-use switchers, so we've provided for that test.

The voltage-level on telephone circuits is 48-volts DC. The wires in the telephone cables are color-coded, with the *green* wire being the positive side, and the *red* wire being the negative side. When there is no load on the line, that is, when all telephones in your home or office are *on hook*, the measured voltage at your telephone's modular connector should be greater than 40-volts DC, give or take a smidgen.

Depending on your particular telephone's repeat coil, your telephone will represent a DC load resistance of approximately 190 to 250 ohms when it goes *off hook*, meaning the handset is lifted from the cradle. Since there is resistance in the wiring between the central office and your telephone, there will be a substantial drop in voltage when your telephone goes off hook. At that time, the voltage at the modular jack might be as low as 5-volts DC. (A Bell System instrument, such as one of the 500 series of telephones, will work even if the line voltage approaches zero volts.) For conventional service a loop voltage of 5 or higher is considered acceptable.

A telephone is made to ring by superimposing a 90-volt, 20-Hz signal on the line. Since a telephone ringer is always connected across the line it represents a continuous AC load on the line. Thus, once again there will be a drop caused by the resistance in the wires between the central office and your phone. A 45-volt RMS equivalent voltage at your telephone is considered acceptable, although 40 volts is sufficient to ring the phone.

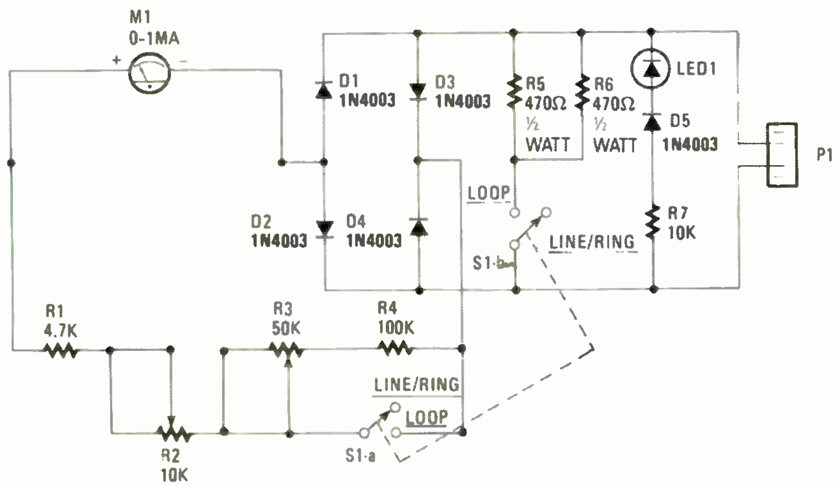


FIG. 1—BY PREVENTING UNNECESSARY SERVICE CALLS, this simple yet effective circuit can save you quite a bit of money.

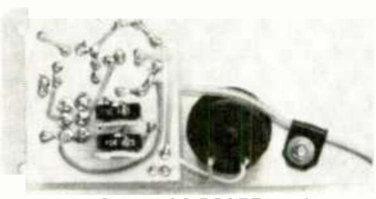


FIG. 2—THE SMALL PC BOARD can be secured to the front panel of the cabinet via S1's mounting nut. The board shown here is the author's prototype.

How it works

The telephone-line tester shown in Fig. 1 is connected to the telephone line through modular connector P1. Although a conventional telephone modular-plug has four connectors, the tester uses only the two inside ones—the red and the green. The yellow and black connectors are not used for normal, single-instrument, two-wire service. Since the tester's LED polarity indicator is always connected when the tester is plugged in, the instant the unit is connected you will have an indication of the polarity. If it is correct—that is, if the green wire is the positive side—and the red wire is the negative side, nothing will happen. If the situation is reversed, the LED will light.

With switch S1 set for LINE/RING, both S1-a and S1-b are open and the meter indicates the condition of the line-voltage. Any line voltage reading in the LINE OK range (more on the meter in a moment) indicates a line voltage higher than 40-volts DC. If the telephone is caused to ring, either by using a ringback number or by dialing from another phone, the meter will indicate RING OK, and the LED will pulse (indicating AC), if the ringing voltage/current is correct. The actual position of the meter's pointer depends on how many ringers are connected across the line. (Three or more of the old-fashioned ringers can excessively load the ringing voltage if the local telephone company has not corrected for your ringer load.)

When S1 is closed the voltage range of the meter is changed and a nominal load resistance of 230 ohms (R5 and R6) is connected across the line to emulate the off hook load of the telephone. If the meter indicates LOOP OK, you can be certain that you have sufficient loop voltage for satisfactory telephone operation. If you place another load on the line, perhaps by taking an extension telephone off hook, the meter reading will almost invariably drop below the LOOP OK range. That is perfectly normal; the line is operating properly when a single loop load results in a LOOP OK meter reading. That, by the way, is how to test telephones for proper connection. If lifting the handset causes the meter reading to drop, you can at least be certain that the telephone's hook switch is working and that the repeat coil is connected to the line.

Building the unit

The unit is assembled on the metal front panel of a 1⅝ × 2⅝ × 5⅛-inch plastic utility box. Except for the meter, all components are installed on a 2 × 2¼-inch printed circuit board that is self-mounting to the panel through S1's mounting nut (see Fig. 2). An appropriate foil pattern for this project is shown in Fig. 3; the parts-placement diagram for that board is shown in Fig. 4. Note that the size of the PC board and its layout aren't really critical as long as the board fits inside the cabinet without interfering with the installation of the meter or the cabinet's internal panel-support posts.

While it is usually best to make circuit boards using the photographic method, because of its small size, this board is an exception. It is probably best to do this layout by hand, using resist tape and resist donuts. That's because the board's small size and relative simplicity make the photographic method too expensive to justify. That's why we've shown the layout here, rather than in our PC service section as usual.

There's just one catch to that—very thin resist tape is getting harder to find in stores all the time. If you can't find the proper tape, we suggest you replace the trace that sweeps around the S1 contacts with a length of No. 24 or No. 26 solid insulated wire. That substitution has been made in the author's prototype to show you the proper routing of the wire. See Fig. 2.

Potentiometers R2 and R3 are installed on the foil side of the board so that they

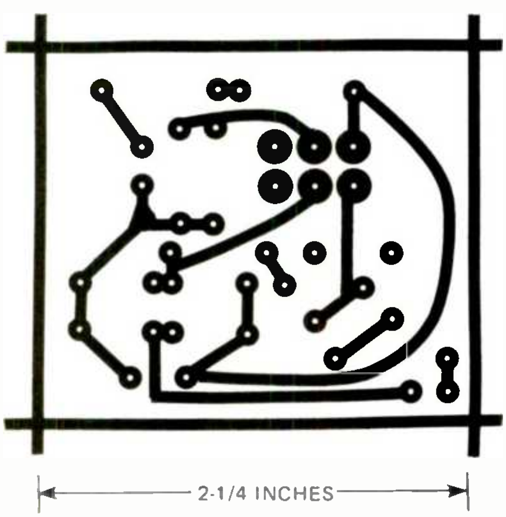


FIG. 3—BECAUSE OF IT'S SMALL SIZE and relative simplicity, the foil pattern for the telephone-line tester is shown here.

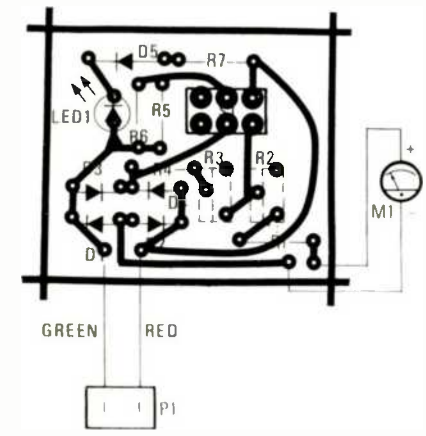


FIG. 4—PARTS-PLACEMENT DIAGRAM for the telephone-line tester. The foil pattern can be found in our PC service section, elsewhere in this issue.

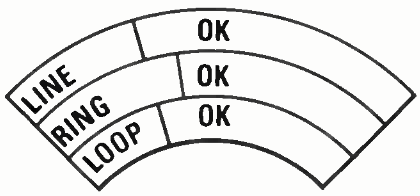


FIG. 5—IF YOU WANT to dress-up the meter, a new scale, similar to the one shown here, can be made. If you choose to do that, be sure that the LINE OK and LOOP OK reference lines fall at the 0.3 mA mark; the RING OK range begins at 0.4 mA.

can be accessed without dismantling the project. All other components are mounted conventionally on the "component" side of the PC-board. To ensure that the LED passes through the panel when the printed-circuit assembly is installed, position the LED so that there is ⅞-inch between the printed circuit board and the bottom of the LED before you solder its leads. When the assembly is secured with S1's mounting nut, ¼ to ½ of the LED will protrude through the front panel.

You might be tempted to substitute a single 230-ohm resistor for R5 and R6. Don't do that! The loop load must be rated for 1 watt, and that is most easily accomplished by using two parallel-connected half-watt standard-value resistors.

Meter M1 in our project is a 0–1-mA DC meter; those are available from almost any electronics supplier. If you want to dress up your project, you can create a meter scale similar to the one shown in Fig. 5. If you do that, the LINE OK and LOOP OK ranges should begin at 0.3 mA. The RING OK range should begin at 0.4 mA. Once you've drawn the scale, remove the meter's plastic cover. Then, taking care not to bend or otherwise damage the meter's needle, glue the new scale in place.

The modular connecting cord can be salvaged from some old telephone gear, or you can get a replacement cord at your local telephone store. With rare exceptions, the cord will have four wires; you will use only the green and red ones, as previously mentioned. Cut the cord to the length you want and then carefully trim the insulation from the free end of the green and red wires. Those of you who haven't worked with old headsets or telephone equipment are in for a surprise, because the wires will appear to be a strand of copper wound around a cotton, polyester or silk thread. That's exactly

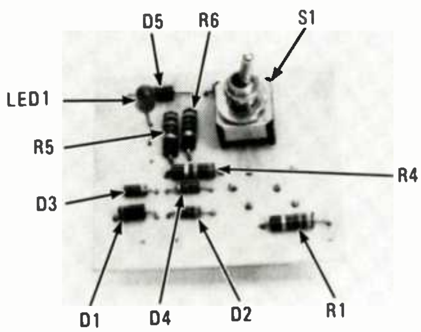


FIG. 6—THE COMPLETED PC board is shown here.

what it is. That type of wire is called "Litz" wire; it is very flexible, but it is almost impossible to solder because the fibers actually burn up before the connection is made. To install the Litz wires on the printed-circuit board, lightly tin the wire using a low-wattage (about 25 watts) soldering iron. Then clip off the very end of the wire so there's no loose strand and pass the wire(s) through its hole in the printed-circuit board. Fold the wire flat against the foil and then quickly solder it in place. If you use too large an iron, or too much heat (you keep the iron on the connection too long), the wire will burn up (turn black) and you'll have to repeat the whole thing until the Litz wires are properly soldered to the printed-circuit foils.

Once you've assembled the board (see Fig. 6), install the meter in the panel, solder the two pieces of wire that will be used to connect the circuit and the meter to the PC board, and then secure the printed-circuit board to the panel, using S1's mounting nut. Finally, connect the free ends of the wire you previously installed to the meter; be sure to observe the proper meter polarity. To prevent the modular cord from eventually breaking at the soldered Litz-wire connections, secure the cord with a plastic cable clamp at one of the meter's mounting screws.

Calibration

Set R2 and R3 to about mid-range, set S1 to the LINE/RING position and then connect a small variable DC power source across the telephone line input. Adjust the power supply for about 40-volts DC and see if the LED turns on. If it does the power supply connections are reversed. If it does not turn on, check its operation by reversing the power connections. If the LED still doesn't turn on you have probably made a wiring error. Once you've determined that the polarity indicator is working normally, return the power-supply connections to normal (LED off).

Next, set the power supply to 5-volts DC, flip S1 to the LOOP position, and adjust R2 until the meter's needle moves to the LOOP OK reference line (reads 0.3 mA). Next, flip S1 back to the LINE/RING position, adjust the power supply for 40-volts DC, and adjust R3 until the meter pointer is on the LINE OK reference line.

PARTS LIST

R1—4700 ohms, ¼ watt, 5%
R2—10,000 ohms, trimmer potentiometer.
R3—50,000 ohms, trimmer potentiometer.
R4—100,000 ohms, ¼ watt, 5%
R5, R6—470 ohms, ½ watt, 5%
D1–D5—1N4003 silicon diode
LED1—jumbo red LED
M1—0–1-mA DC panel meter
S1—DPST, miniature, PC mount
P1—Modular telephone connector.
Miscellaneous—Cabinet, PC board, wire, solder, etc.

Testing the line

To test a telephone line simply set S1 to the LINE/RING position and connect the tester to the telephone line. If the LED lights, the telephone company's wiring to the connector is reversed (it does happen). Note the meter reading—the pointer should rest anywhere in the ok range (read 0.3 mA or greater). Next, flip S1 to the LOOP position; again, the meter should read in the ok area. Finally, once again set S1 to the LINE/RING position and cause the line to ring (perhaps by dialing from another phone). The meter should read in the RING OK range (greater than 0.4 mA) and the LED should blink because the voltage applied to the polarity-tester circuit is AC. If any of the tests produces anything but the expected results, the problem most likely lies in the telephone lines rather than in the phone itself.

If you want to check out extension telephones, set S1 for a LOOP test and then lift the handset of any phone; the meter should indicate less than the OK reading when the telephone goes off hook. As we said earlier, that is normal and shows that the telephone is at least connected to the line.

The telephone-line tester we've described is limited; it can not tell you precisely what's wrong with your telephone service. But it can at least tell you roughly where the trouble lies, and hence who to call to have repairs done. Considering the high cost of an unnecessary service call, that puts you way ahead in the game. **R-E**

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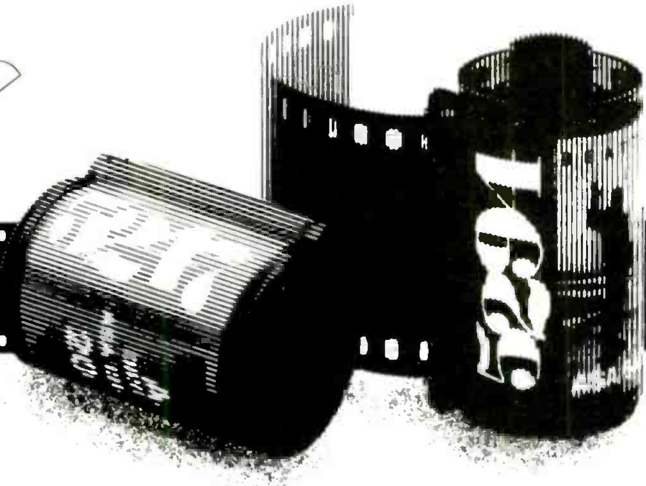

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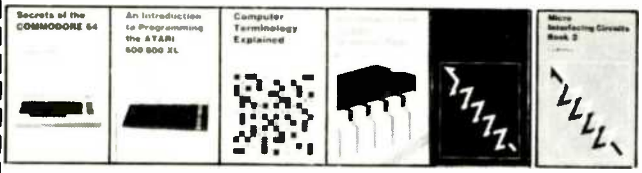

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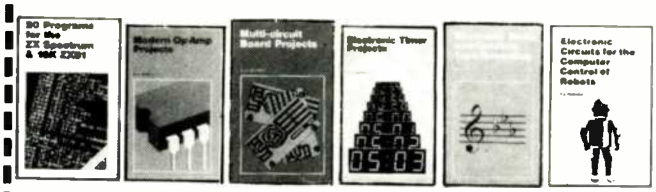

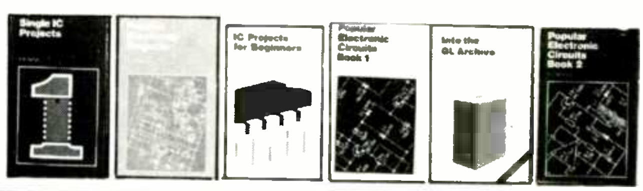

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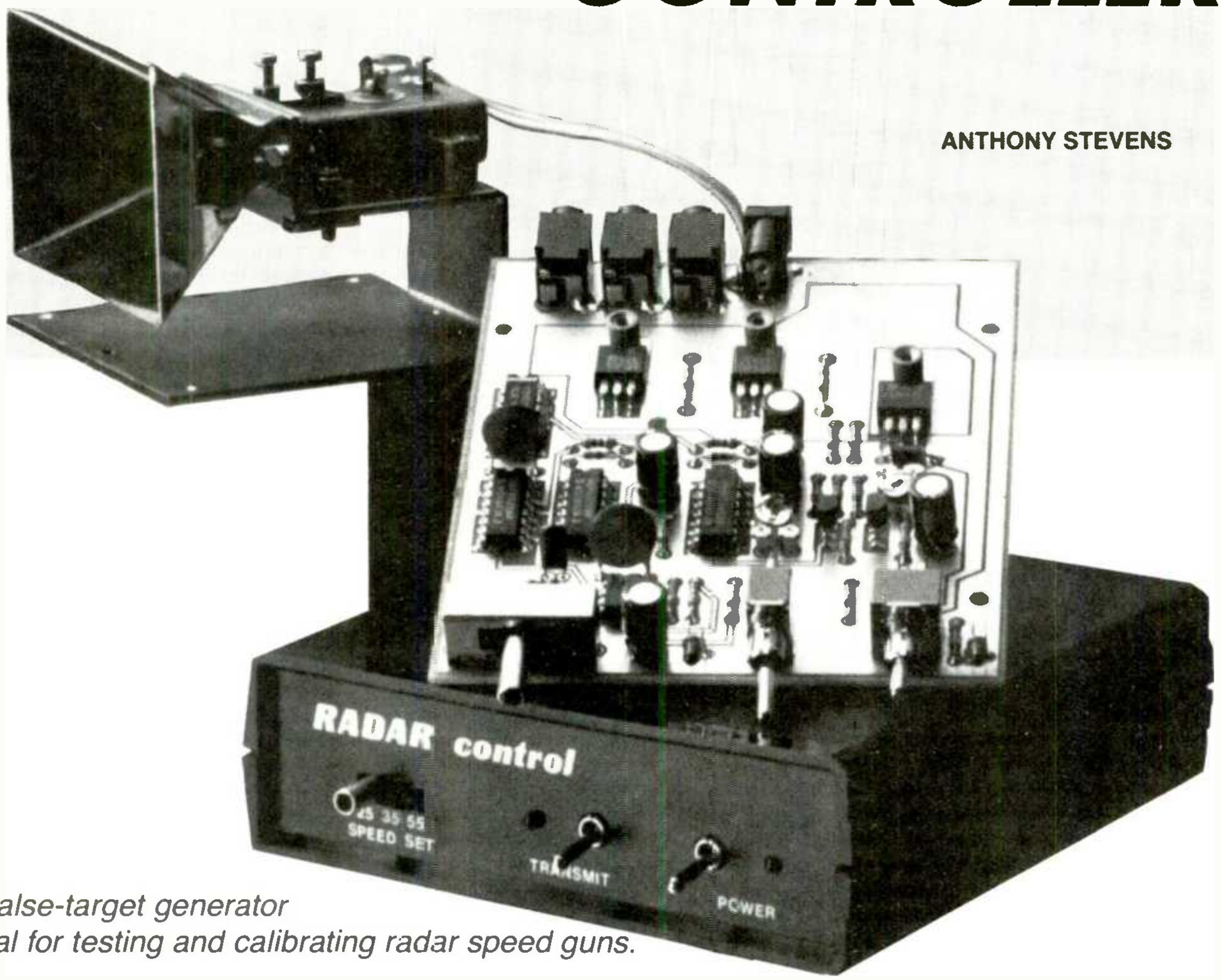


ANTHONY STEVENS

This false-target generator is ideal for testing and calibrating radar speed guns.

SINCE THE FCC HAS ALLOWED THE COMmercial and private use of some radar frequencies, interest in those frequencies has greatly increased. Amateur-radio operators are actively experimenting with radar for communications. On the commercial front, the burglar-alarm industry has turned to radar for intrusion-detection alarms. Boaters are using radar to guide their crafts through hazardous fog. Even professional baseball teams are getting into the act with radar guns being used to time the speed of their pitchers' deliveries. And of course everyone is familiar with radar through its use by highway police to enforce the speed limit.

As with all other electronics equipment, radar guns need to be calibrated and tested periodically for accuracy. Here is an inexpensive portable calibrator for radar equipment. It works by generating a false target.

Radar false-target generators are used by the military as electronic camouflage on our stealth aircraft to fool the enemy's radar-tracking missiles. A similar technique is used in this radar gun calibrator. To better understand the technique, we should first understand how radar speed-guns work.

How radar works

The police have been using radar to measure vehicle speed since the late 1940's. A block diagram of a typical radar speed-gun is shown in Fig. 1.

A radar gun uses the *Doppler effect* to determine the speed of a moving object. Its output consists of a steady, unmodulated carrier. The signal travels in a tight beam toward a target whose speed is being monitored. That target can be any object, such as a speeding baseball—or a speeding motorist. Because of the nature of microwave transmissions, the signals are reflected by the target back toward their source.

Because of the Doppler effect, the frequency of the reflected signal is slightly higher than the original transmitted signal. For each mile per hour an object is travelling toward the radar speed-gun, the reflected signal received by the gun will be shifted about 31 Hz higher. In the radar gun, the return signal is mixed with a sample of the original transmitted wave to produce a difference frequency. That difference frequency is analyzed and converted to produce a direct readout of speed.

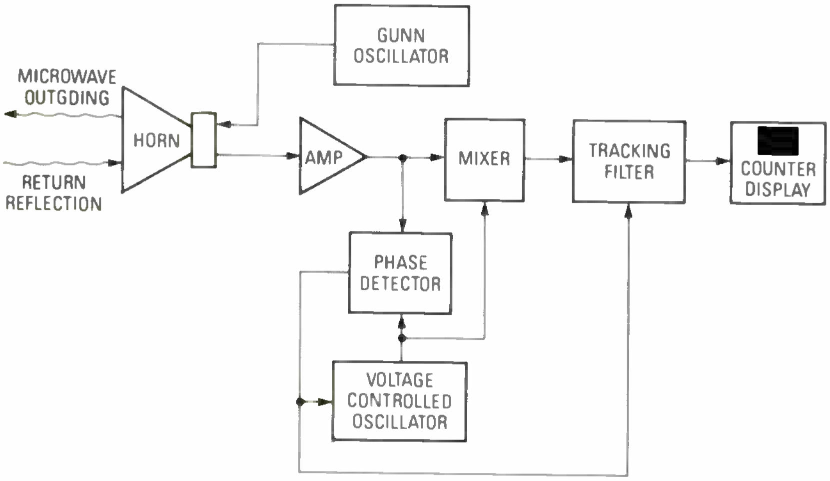


FIG. 1—SPEEDING FASTBALLS, or speeding motorists, can be timed using a radar speed-gun. A block diagram of such a unit is shown here.

WARNING

This radar calibrator may interfere with police radar, CB units, radio receivers, etc., up to 1000 feet away. Thus its use should be restricted to laboratory use or for educational, scientific, informational, or calibration purposes. The illegal use of a transmitter can subject the user to a $10,000 fine, a jail term, and the seizure of transmitting equipment.

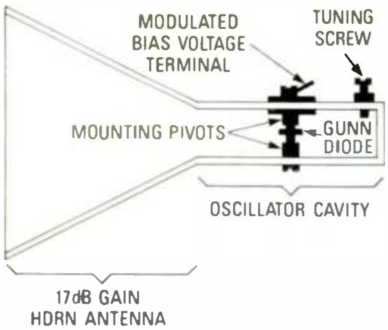


FIG. 2—THE HEART OF A RADAR SPEED-GUN used by the police, and others, or a radar false-target generator is a microwave Gunn diode. Here, the proper way to mount such a diode in a microwave horn is shown.

As shown in Fig. 2, the heart of a radar speed-gun—and our radar calibrator—is a Gunn diode oscillator. Typically those oscillators can generate an output level of about 100 mW. With that output level, and with a highly directional transmitting antenna, the range of a radar speed-gun is about ⅓ of a mile.

Until recently, high-output Gunn diodes were expensive; most cost several hundred dollars or more. Now, however, a Gunn diode can be obtained for as little as $60. That certainly makes it attractive to hobbyists for experimentation.

How the calibrator works

Our circuit generates a false target that can be used to calibrate radar speed-guns, such as those used to time the speed of a baseball player's throw. Let's examine Fig. 3 to see how the calibrator can be made to force a speed gun to read a desired speed. As is shown in Fig. 3-*a*, the outgoing reference transmission and the incoming reflected transmission are both present inside the antenna cavity. Because, as described earlier, they are of slightly different frequencies, they interfere with each other in such a way that a difference signal (at a *beat frequency*) is created. That signal is detected by a mixing diode, and the low-frequency beat that results is passed on to be analyzed.

To force a speed gun to read a particular speed, all a false-target generator need do is to produce a difference signal that simulates the one that would be created by an object travelling at a certain speed. See Fig. 3-*b*. Assuming the output-power level is sufficient, it will "capture" the receiver, preventing it from detecting any other signal that might be present, including the Doppler-shifted reflection.

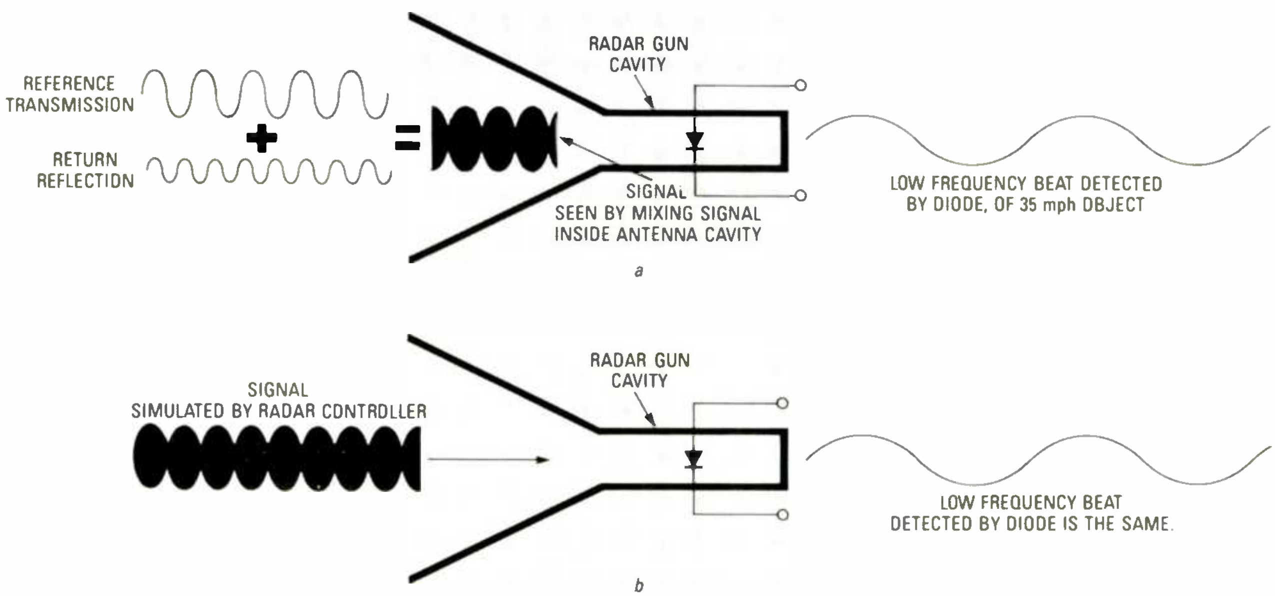


FIG. 3—WHEN THE TRANSMITTED AND REFLECTED SIGNALS are mixed in the horn's cavity, the resulting low-frequency beat can be used to determine the speed of the reflecting object, as shown in *a*. The calibrator works by generating a signal that simulates the one that would result if the transmitted signal were reflected by an object moving at a specified speed, as shown in *b*. As a result, the low frequency beat detected by the diode is the same as the one in *a*.

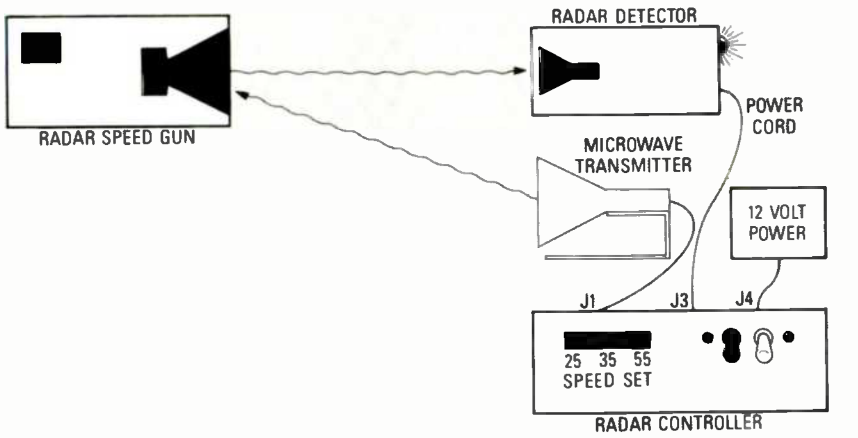


FIG. 4—USE THIS SET-UP to calibrate a radar-speed gun. The speed gun can be forced to read 25, 35, or 55 miles-per-hour by altering the setting of a switch on the calibrator.

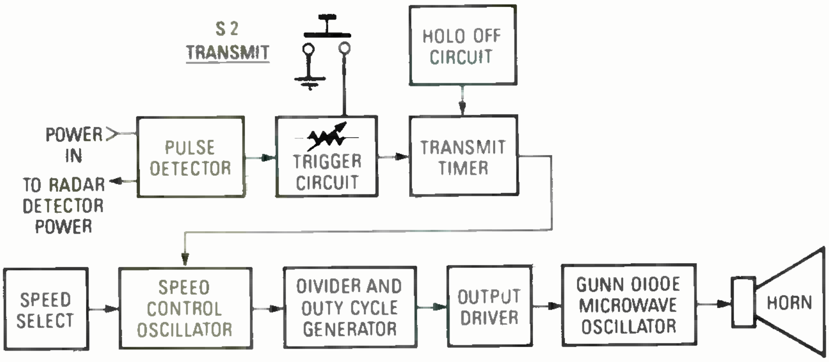


FIG. 5—THE RADAR CALIBRATOR is shown here in block diagram form.

Creating a difference signal that causes a speed gun to read a desired speed is not difficult. It's done by pulsing a carrier whose frequency is in the passband of the speed gun's receiver. Speed is simulated by varying the pulse rate. That is, the pulse rate is set at 31.4 pulses-per-second per mile-per-hour of desired reading. For a desired reading of 55 miles-per-hour the pulse rate would be 31.4 × 55 = 1727 pulses-per-second.

The basic set-up for calibrating a radar gun is shown in Fig. 4. A block diagram of the false-target generator is shown in Fig. 5. Note that the false-target generator is designed to work in conjunction with an automotive radar detector. The radar detector is used to make the operation of the calibrator almost automatic. When the radar detector senses a transmission from a speed gun, it sounds a buzzer or turns on a light as a warning. In doing that, the detector draws more current than normal from its 12-volt power source. The false-target generator's pulse-detector circuitry detects that surge, amplifies it, and, via the trigger circuit, triggers the transmit timer. The timer turns on the speed-control oscillator for approximately ten seconds. Using such a short transmission time is necessary to keep the Gunn diode from overheating.

A manual TRANSMIT switch (S2) is included for those not wanting to use a radar detector to trigger the Gunn oscillator. The switch is a momentary type, and it also triggers the one-shot for ten seconds.

The speed-control oscillator drives a divider network that generates the appropriate frequency and duty cycle for the output driver, which supplies voltage to the Gann-diode oscillator. After ten seconds the transmitter timer locks itself off for a couple of seconds to give the radar detector time to settle down and reset.

About the circuit

The schematic diagram of the calibrator is shown in Fig. 6. Power is applied through J4. Power switch S1 applies power to the internal circuit through IC6, an LM317 voltage regulator; power is also applied to J3, the V_{OUT} jack, through R2, a 1-ohm sensing resistor. The voltage drop across R2 is amplified by Q1, which is slightly forward biased by R16, the TRIGGER SENSITIVITY control. Transistor Q2 amplifies the trigger signal and applies it to pin 5 (the trigger input) of one half of IC2, a 4538 dual timer. That half of the timer package is configured as a one-shot with a period of about ten seconds.

The period of the other half of IC2 is determined by C3, R19, and R11. The output of that timer, pin 9, is used to reset the first timer via pin 3. Trimmer R11 is used to adjust the hold-off time of the trigger circuit to prevent false retriggering. False retriggering can occur when the calibrator output-signal is detected by the radar detector, which in turn retriggers the calibrator. You will have to experiment with R11 to find the setting that will prevent false retriggering.

The output of the first half of the 4538, pin 6, is used to enable IC1, a 555 timer that's configured as an astable multivibrator. The oscillating frequency of IC1 is determined by R6, R7, R8, and C8. The

PARTS LIST

All resistors ¼-watt, 5%, carbon film unless otherwise noted
R1—4700 ohms
R2, R24, R25—1 ohm
R3, R10—10,000 ohms
R4, R21—2200 ohms
R5—2000 ohms, 1%
R6—6650 ohms, 1%
R7—4420 ohms, 1%
R8—2210 ohms, 1%
R9, R15, R22, R23—1000 ohms
R11—1 megohm, trimmer potentiometer
R12, R18, R19—100,000 ohms
R13—1 megohm
R14, R17—47,000 ohms
R16—5000 ohms, trimmer potentiometer
R20—270 ohms
Capacitors
C1–C5—10 µF, 25 volts, electrolytic
C6, C7—0.1 µF, ceramic disk
C8—470 pF, 5%, 100 volts, mylar
C9—0.0047 µF, 100 volts, mylar
Semiconductors
IC1—555 timer
IC2—4538B dual precision timer
IC3, IC4—4522B decimal divide-by-N counter
IC5—4518B dual synchronous divide-by-10 counter
IC6—LM317 voltage regulator
Q1—2N3906 PNP transistor
Q2, Q3—2N3904 NPN transistor
Q4, Q5—TIP120 NPN power transistor
D1—1N4004
D2, D3—1N4148
D4—MA49159, Gunn diode
LED1, LED2—Red LED
Other Components
S1—DPDT, 3 amps, 110 volts
S2—SPDT, momentary toggle
S3—DP4T, slide switch
J1, J2, J3—3.5 mm phone jack
J4—2.1 mm phone jack
Miscellaneous: PC board, hardware (7 each—4-40 screws, 3 each—4-40 nuts), microwave horn, case, wire, solder, etc.
The following are available from Microwave Control, 1701 Broadway, Suite 236, Vancouver, WA 98663. (1-260-693-6843): Complete kit including tested Gunn diode, microwave horn, PC board, case, and all parts, $169.50; tested Gunn diode, microwave horn, $117.00; etched and drilled PC board, $19.50. Please add $4.50 for shipping and handling. Washington state residents add 7.4% for sales tax. Allow 4-6 weeks for delivery.

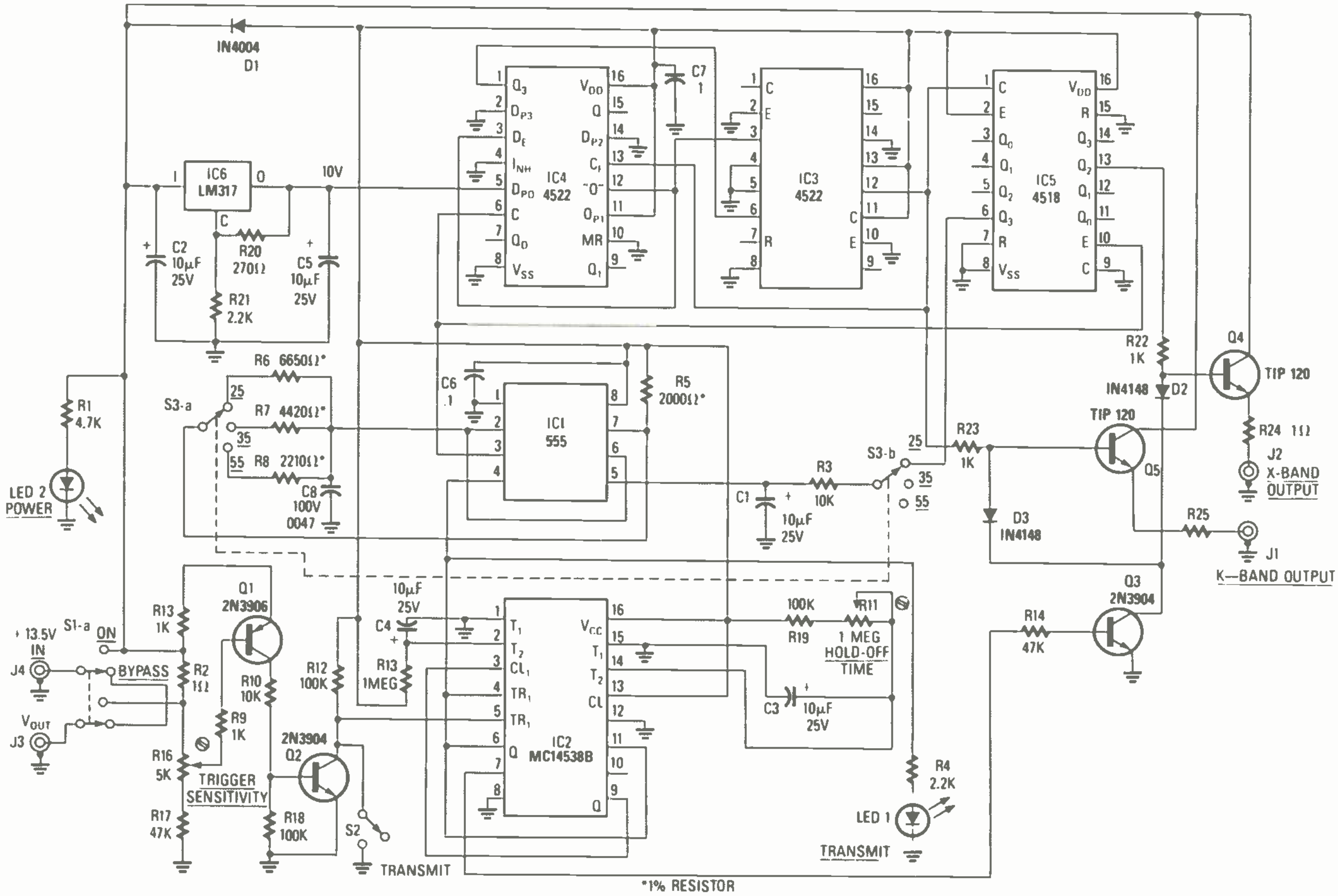


FIG. 6—ONE OUTPUT OF THE radar-calibrator circuit (J1 or J2) is fed to a Gunn diode mounted in a microwave horn. Outputs are provided for each of the two most popular speed-gun frequencies.

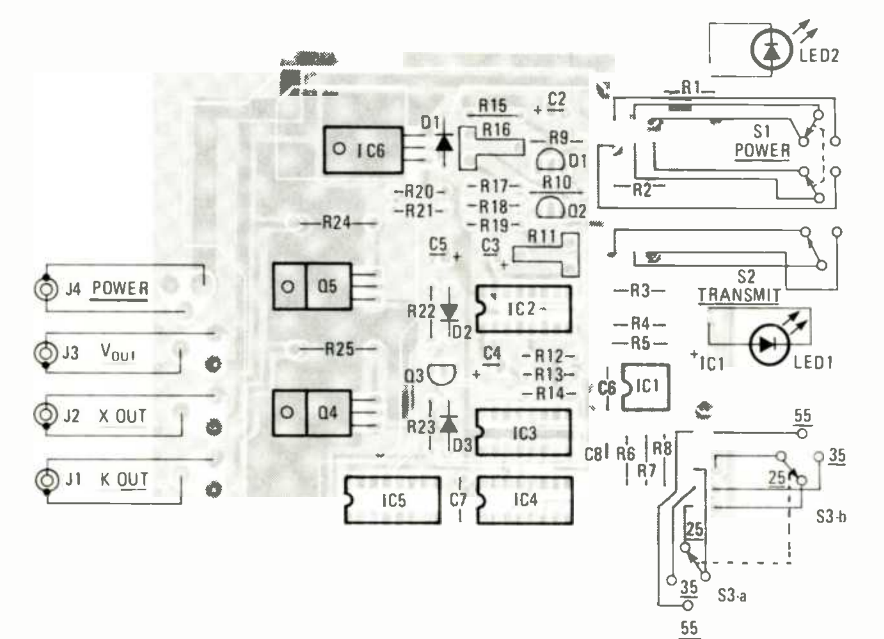


FIG. 7—THE CIRCUIT SHOULD BE MOUNTED on a double-sided PC board. The patterns can be found in the PC Service section, of this magazine.

output of the oscillator drives the divider string consisting of IC4, IC3, and IC5.

The output from each divider is a square-wave with a 40% duty cycle.

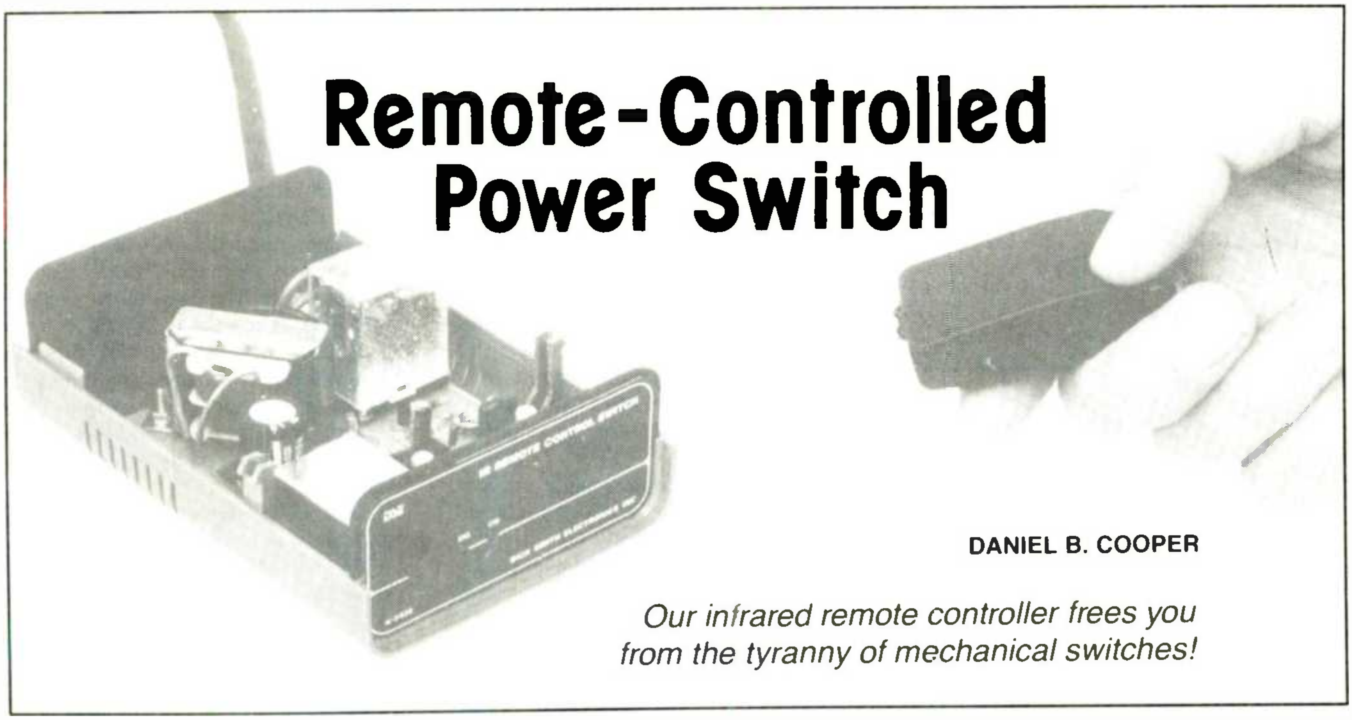
There are two outputs taken from the divider string. One, taken from pin 13 of IC5, is emitter coupled to J2, X-BAND OUTPUT, via driver transistor Q1. The 1-ohm resistor, R24, is included to ensure stability. The other output, taken from pin 13 of IC3, is emitter coupled to J1, K-BAND OUTPUT, via driver transistor Q2. A 1-ohm resistor, R25, is included to ensure stability. The J1 or J2 output, as appropriate, is applied to the Gunn diode. Although optional, and not shown in the illustrations, for best results a small, 0.47-pF mylar capacitor, C9, should be installed across the Gunn diode.

Diodes D2 and D3, in conjunction with transistor Q3, help ensure that the driver transistors remain off when the unit is not triggered. When switch S1 is at its slow speed settings, 25 35, the output if IC5 is divided further and fed back through R3 and C1 to modulate IC1.

Building the unit

We recommend the use of a printed-circuit board. If you wish to etch your own, an appropriate double-sided layout is provided in our PC Service section. Also, you can purchase a board from the supplier mentioned in the Parts List.

continued on page 134



Remote-Controlled Power Switch

DANIEL B. COOPER

Our infrared remote controller frees you from the tyranny of mechanical switches!

IT SEEMS A CRIME THAT SLEEK, SEXY stereos, VCR's and other electronic appliances must be operated by something so crude as a mechanical switch. There's really nothing wrong with a switch, but you must be within arm's reach to operate it. And when you're sitting comfortably in an easy chair and want to turn a TV, a stereo, or a lamp across the room on or off, it's mighty inconvenient to have to stand up, walk over to the device, and flip its switch.

Of course, if you're fortunate enough to own a remote-controlled TV or stereo, then you're *partly* free of the tyranny of mechanical switches. But what about radios, lamps, and the myriad of other devices that must be operated manually?

We've got the solution. The easy-to-build IR (*I*nfra-*R*ed) control system described here can be built for under $40. You can then control any device that draws as much as 1500 watts of power. The device can be 30 or more feet away.

Our controller consists of a *very* small (2 × 1½ by ½ inches) battery-powered transmitter and an AC-powered receiver that measures only 5½ × 3½ × 1½ inches. To use the controller, just plug the receiver into a wall outlet near the device you want to control, and then plug that device into the receiver. Then use the hand-held transmitter to turn the device on and off at your convenience. That's all there is to it!

How it works

The schematic diagram of the transmitter is shown in Fig. 1. As you can see, the transmitter is built around two CMOS 555 timer IC's (TLC555's). The TLC555 is quite similar to its bipolar cousin, but it requires less than 100 μA of supply current, and that's important when a circuit must be powered from a very small battery, as our transmitter is.

The transmitter generates a modulated 35-kHz IR signal. The 35-kHz carrier frequency is generated by IC2, and the 1500-Hz modulating signal is generated by IC1. The 1500-Hz output of IC1 appears as in Fig. 2-*a*; the modulated output of IC2 appears as in Fig. 2-*b*. An expanded view of each spike in that waveform is shown in Fig. 2-*c*.

The output of IC2 drives LED1 through resistor R5; that LED provides visual indication that the transmitter is working. In addition, IC2 drives transistor Q1, which in turn drives the two infrared LED's (LED2 and LED3).

The transmitter is powered by a miniature 12-volt battery, which is sometimes called a "lighter" battery from its use in electronically-ignited cigarette lighters. Although the battery supplies sufficient voltage for the circuit and is small enough to fit in a tiny case, it cannot directly source the high current needed to drive the two IR LED's. To provide that current, we pre-charge capacitor C6 and then dump all the charge it contains when S1 is pressed. When S1 is not pressed, power to the IC's is cut off. However, C6 is kept charged via R8. Then, when S1 is pressed, the current stored in C6 can be used to drive the LED's for as much as ½ second. That's plenty of time for the receiver to pick up a signal.

When C6's charge is exhausted, the

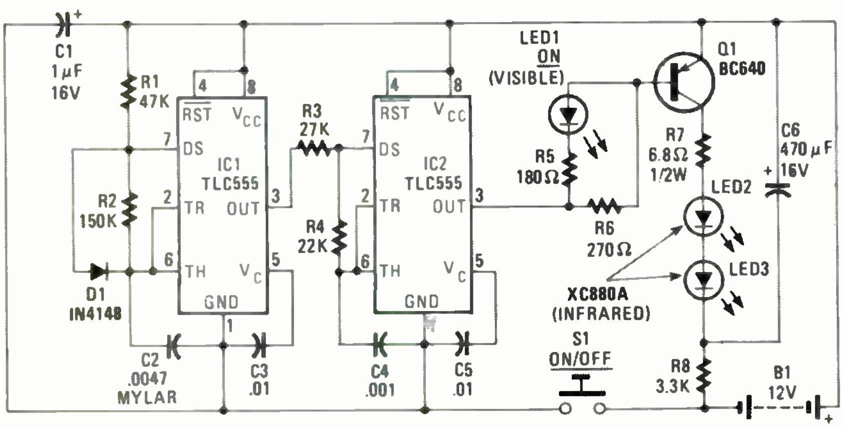


FIG. 1—THE TRANSMITTER IS BUILT AROUND TWO CMOS 555's that generate a modulated 35-kHz signal; that signal is transmitted by the two infrared LED's, LED2 and LED3.

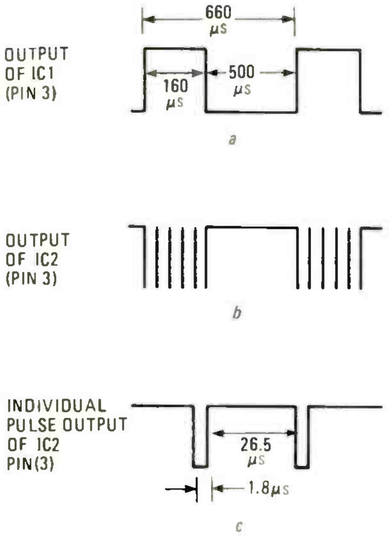


FIG. 2—THE 1500-Hz MODULATING SIGNAL is shown in *a*; the modulated 35-kHz carrier signal is shown in *b*; and one cycle of the 35-kHz bursts is shown in *c*.

output of the LED's drops to about one-third of their peak power. When S1 is released, C6 begins to recharge; it reaches 90% of capacity in about one second, and full capacity in five to six seconds.

At distances under ten feet, that charge time will be of no consequence because, at that distance, the receiver can pick up the reduced signal. At greater distances, though, it may be impossible for the receiver to respond twice in a very short period of time—less than about a second. But you should have no trouble if you wait for several seconds between each use of the transmitter.

The receiver

It is relatively easy to design an IR remote-control system, but most simple designs are hampered by either low sensitivity or high susceptibility to noise. The outstanding feature of our receiver is its high-sensitivity, low-noise input preamplifier, which is built around an µPC1373 IR remote-control preamplifier (IC1 in Fig. 3).

The IC is contained in an eight-pin SIP (*S*ingle *I*nline *P*ackage), and it incorporates circuitry that not only conditions a signal from a photodiode, but also varies the bias on the diode to accommodate changing lighting conditions. The µPC1373 also has a sensitive 30–40 kHz tuned detector, automatic gain control, a peak detector, and an output waveshaping buffer.

All that circuitry allows the the weak signal picked up from photodiode D2 to be output as a clean, logic-level demodulated signal; that signal is, in fact, an exact replica of the signal produced by IC1 in the transmitter!

The preamp stage is very sensitive to various forms of noise and RF interference, so, for maximum accuracy, the entire preamp circuit should be shielded and bypassed. Our PC-board layout, discussed below, has been optimized for low-noise performance.

The demodulated signal from the preamp stage is sent to IC4-a, a 74C14 Schmitt trigger. The squared-up 1500-Hz signal is then sent to the clock input of IC5-a, half of a 4013 dual "D" flip-flop. The flip-flop is configured as a binary divider, so the frequency of its output signal is exactly half the frequency of its input signal, but it has a duty cycle of exactly 50%.

That 750-Hz signal is clipped to approximately 0.7 volts p-p by diodes D3 and D4. The clipped signal is then fed to IC6, a 567 tone decoder. The output of that IC goes low whenever the frequency of the signal fed to it is within its lock range—the range of frequencies within which the IC will respond—of its internal VCO (*V*oltage-*C*ontrolled *O*scillator).

The center of the VCO's lock range is set by components R16, R17, and C17. The trimmer potentiometer (R16) allows

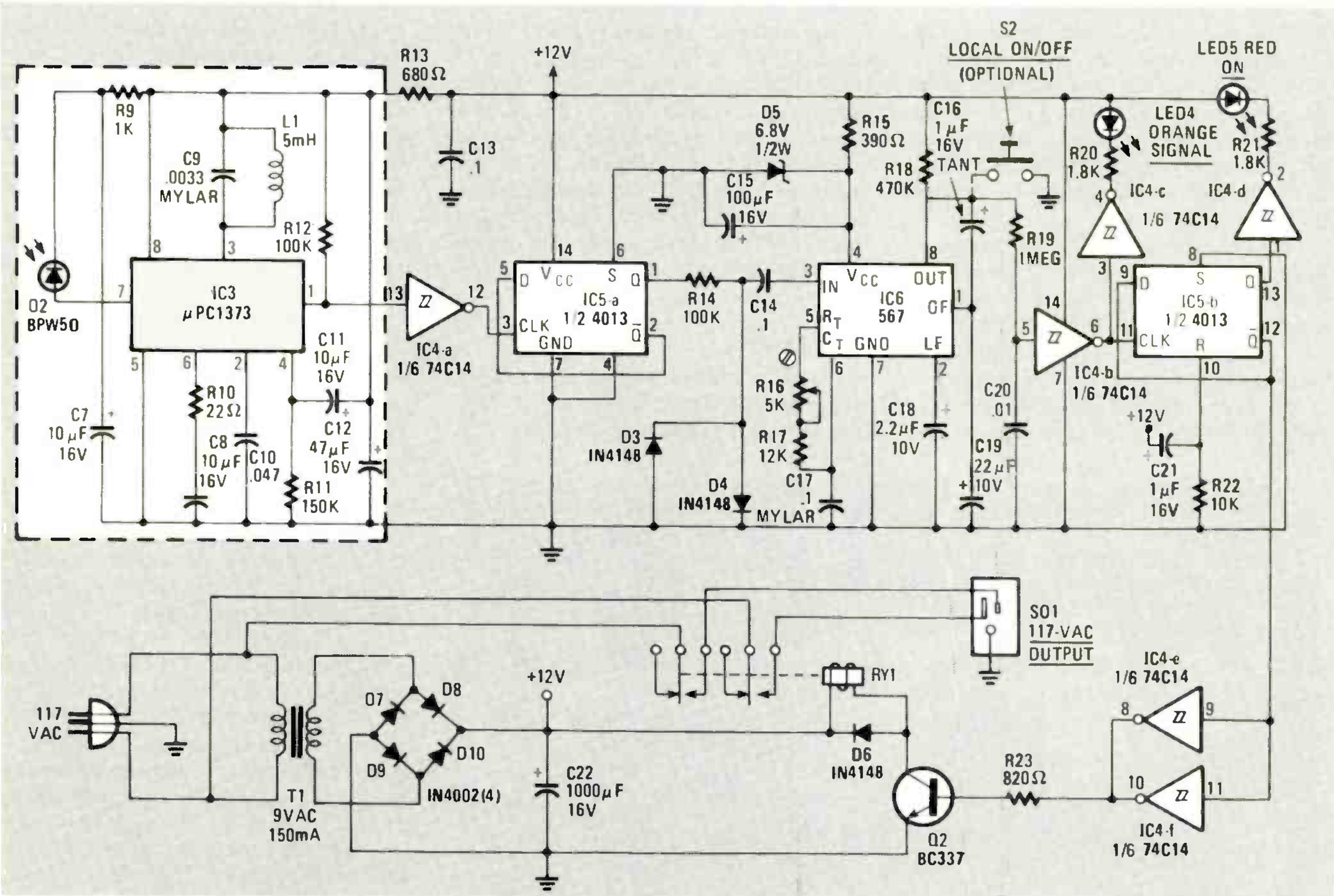


FIG. 3—THE RECEIVER FEATURES A SHIELDED PREAMP, shown here inside the dashed lines. The output of the preamp is squared up and fed to a PLL tone-decoder (IC6); the output of the PLL is fed through a bi-stable latch (IC5-b), which provides the ON/OFF function.

you to vary the center frequency to match the output of your transmitter. The lock range of the VCO is set by C18. We use a 2.2 µF capacitor here for a moderately narrow lock range—about 110 Hz. That provides an overall range of 750 Hz ±55 Hz. The length of time a signal of that frequency must be present to obtain output is set by capacitor C19; the 22-µF value sets that time at about 10 ms.

When IC6 detects a signal of the proper frequency, pin 8 goes low. Since that output is an open-collector transistor, a pull-up resistor (R18) is required for proper operation. The output signal is fed through another Schmitt trigger (IC4-b), which drives another "D" flip-flop, IC5-b. That flip-flop is configured as a bistable latch; each successive input causes the output to change state.

Schmitt trigger IC4-b also drives IC4-c, which in turn drives LED4, SIGNAL, which lights up whenever a signal is received. The Q output of IC5-b drives IC4-d, which in turn drives LED5, ON, which lights up whenever the output is in the *on* state. The $\overline{Q}$ output of IC5-b drives two parallel-connected inverters, IC4-e and IC4-f; they turn transistor Q2 on when $\overline{Q}$ goes low. That transistor energizes the relay; its contacts switch the device you're controlling on and off. Diode D6 is wired across the coil of the relay to suppress the reverse spikes generated by the coil whenever it is de-energized. Without D6, Q2 might be destroyed.

Components C21 and R22 are connected to the latch's R input; they provide a power-on-reset function. In other words, they ensure that the relay will be off when power is first applied to the receiver. At power-up, C21 is effectively a short circuit, so R is high. In that reset state, the Q output of the flip-flop is low, the $\overline{Q}$ output is high, so Q2 and the relay are off. But, as C21 charges through R22, the voltage across C21 increases, and eventually the R input drops to ground and allows the IC to respond to input signals.

We have made provision for an optional LOCAL ON/OFF switch, S2. Since the 567 has an open-collector output, S2 can be used to force the inverter's input low and thus alternate the state of the latch without damaging the 567.

The receiver is powered by a nine-volt, 150-mA transformer that delivers about 12-volts DC after rectification by diodes D7–D10 and filtering by C22. Since most of the receiver circuit is voltage-independent, no regulator is used. However, the 567 requires a supply voltage less than nine volts. Therefore, resistor R15, capacitor C15, and Zener diode D5 are used to provide a regulated, filtered 6.8-volt DC source.

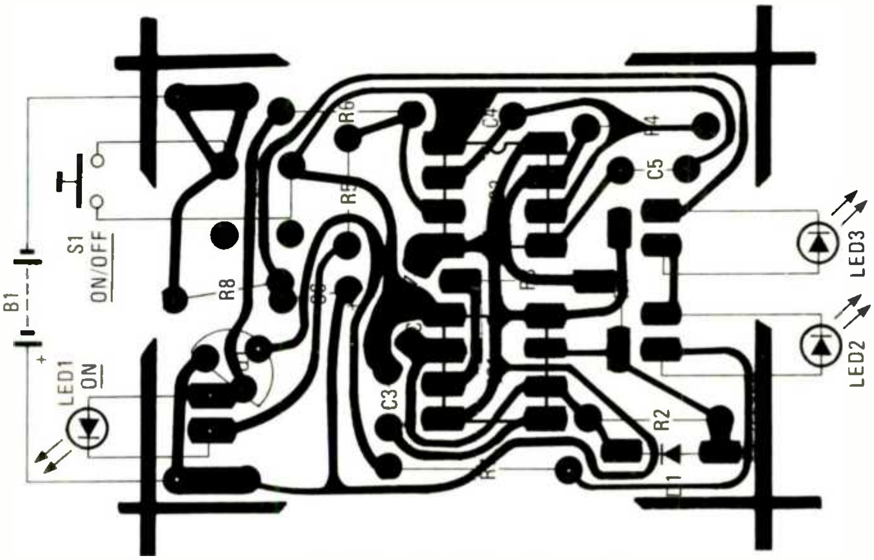


FIG. 4—COMPONENTS MOUNT ON THE TRANSMITTER BOARD as shown here.

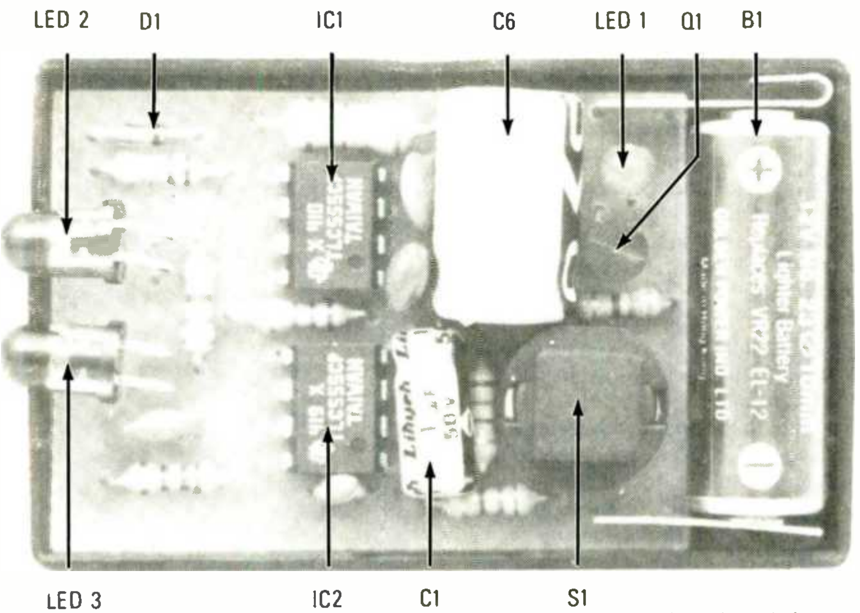


FIG. 5—THE COMPLETED TRANSMITTER appears as shown here. The legs of the electrolytic capacitors (C1 and C6) must be bent horizontally for those capacitors to fit in the case.

Construction

We recommend that you use PC boards, especially for the receiver, as the performance of its preamp can be degraded by improper layout. You can etch your own boards using the foil patterns shown in PC Service; pre-etched boards are included with the kits sold by the source mentioned in the Parts List.

When your boards are etched, inspect them for shorts and opens. Correct any problems and clean the boards with steel wool. Now build the transmitter. Install all components except the battery clips and the three LED's according to the diagram in Fig. 4. Take care to orient the capacitors, the IC's, D1, and Q1 correctly. As you can see in Fig. 5, the leads of C1 and C6 must be bent at a right angle; the capacitors are then mounted horizontally. The flat edge of S1 should face Q1.

Next solder the battery clips to the board. The bump on the negative clip should face inward, and the hook on the positive clip should face outward. Now insert LED1 into its holes with the flat side toward the positive battery clip, but do not solder it in place yet. Lay the PC board in the top half of the case, adjust the position of the LED to line up with its mounting hole, and then solder the LED in place.

Now insert the two IR LED's (LED2 and LED3) into their holes with their flat sides toward the side of the board the negative battery clip is mounted on. Solder them in place about ⅜ inch above the surface of the PC board. Carefully bend their leads so that they are parallel with the board and with each other, and so that the center of each LED is about 5/16 inch above the surface of the board.

Lay the board in the lower half of the case and carefully mark where the center of each LED touches the front edge of the case. Remove the board and use a small rattail file or a similar tool to cut out a precise half-circle for each LED. Check your progress often to avoid overcutting.

Snap both halves of the case together without the board in place and mark where the edges of the holes meet the upper half of the case. Take the case apart and carefully file out the holes in the upper half to match those in the lower half of the case.

Now lay the board in the case. Then insert B1 and press S1; LED1 should remain lit for as long as S1 is pressed. If the LED doesn't light, make sure the battery is inserted correctly. If it is, use a frequency counter or an oscilloscope to verify that both TLC555's are oscillating. If they are, make sure that LED1 is mounted correctly. If you still haven't isolated the problem, you may have installed Q1 incorrectly, or you may have installed Q2 by mistake.

When the board is debugged, complete assembly of the transmitter. Insert the board into the lower half of the case and then snap both halves together. If desired, the IR LED's can be pushed back into the case so that they do not protrude.

Building the receiver

Since the components are not so closely spaced, building the receiver is somewhat easier. Referring to Fig. 6, solder all electronic—not mechanical—components to the board, except for LED4, LED5, D2, and T1. Be careful to orient all polarized devices correctly; IC3 should be mounted with the bevel oriented toward the transformer. Don't forget to solder the jumpers in place.

Bolt T1 to the board with its secondary wires toward C22. Keeping the leads as short as possible, solder the primary and the secondary wires to the appropriate pads. To prevent shorts, ensure that all strands of each wire pass through its hole. Clip off and insulate the transformer's center tap.

Solder three 3-inch pieces of 18-gauge wire to the output pads near the relay. Connect the opposite ends of those wires to the appropriate terminals on SO1.

Now solder D2 in place with its base about ⅛ inch above the surface of the board and with the beveled corner toward the center of the board. Mount LED4 and LED5 with their flat sides facing each other; the center of each LED should be about ¼ inch above the board. The LED's will be parallel to the board and to each other if they are mounted correctly.

Now solder four thick pieces of bus wire to the four holes where the shield will mount. The shield can be bent as shown in Fig. 7 from a thin piece of tin. Also, cut a ⅞- × 1⅝-inch piece of tin plate for the bottom of the PC board. However, don't solder either shield in place until you have verified that the preamp circuit works exactly as intended.

Strip the sheath of the AC cord so that one inch of each conductor protrudes; strip, twist, and tin ¼ inch of each conductor. Pass the cord through the rear panel, insulate it with a grommet, and solder the leads to the board. Then press SO1 into the rear panel and solder the three wires to the correct terminals. Your receiver should resemble the one shown in Fig. 8.

Now insert the red plastic IR filter into the front panel so that its legs are horizon-

continued on page 134

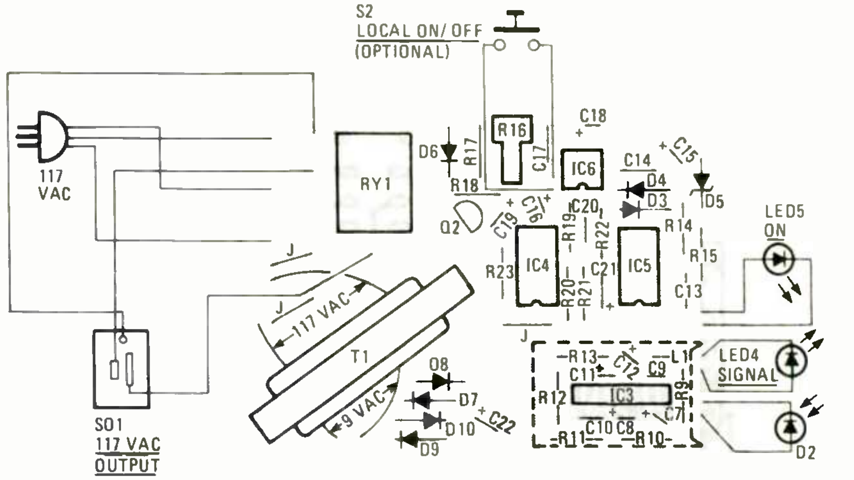


FIG. 6—COMPONENTS MOUNT ON THE RECEIVER BOARD as shown here. One shield must be soldered to each side of the board after testing confirms that the preamplifier works.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1—47,000 ohms
R2, R11—150,000 ohms
R3—27,000 ohms
R4—2200 ohms
R5—180 ohms
R6—270 ohms
R7—6.8 ohms, ½-watt
R8—3300 ohms
R9—1000 ohms
R10—22 ohms
R12, R14—100,000 ohms
R13—680 ohms
R15—390 ohms
R16—5000 ohms, trimmer potentiometer
R17—12,000 ohms
R18—470,000 ohms
R19—1 megohm
R20, R21—1800 ohms
R22—10,000 ohms
R23—820 ohms

Capacitors

C1—1 µF, 16 volts, electrolytic
C2—0.0047 µF, mylar
C3, C5, C20—0.01 µF, ceramic disc
C4—0.001 µF, ceramic disc
C6—470 µF, 16 volts, electrolytic
C7, C8, C11—10 µF, 16 volts, electrolytic
C9—0.0033 µF, mylar
C10—0.047 µF, ceramic disc
C12—47 µF, 16 volts, electrolytic
C13, C14—0.1 µF, ceramic disc
C15—100 µF, 16 volts, electrolytic
C16—1 µF, 16 volts, tantalum
C17—0.1 µF, mylar
C18—2.2 µF, 10 volts, electrolytic
C19—22 µF, 10 volts, electrolytic
C21—1 µF, 16 volts, electrolytic
C22—1000 µF, 16 volts, electrolytic

Semiconductors

IC1, IC2—TLC555, CMOS 555 timer
IC3—µPC1373, IR photodiode preamplifier
IC4—74C14, hex Schmitt trigger
IC5—4013, dual "D" flip-flop
IC6—567, tone decoder
D1, D3, D4, D6—1N4148, signal diode
D2—BPW50, infrared photodiode
D5—1N5526A, 6.8-volt, 400-mW, Zener diode
D7–D10—1N4002, rectifier diode
LED1—visible miniature red LED
LED2, LED3—XC880A, infrared LED
LED4—visible miniature orange LED
LED5—visible miniature red LED
Q1—BC640 (ECG383)
Q2—BC337 (ECG159)

Other components

B1—12-volt miniature "lighter" battery
RY1—relay, DPDT, 10-amps, 12-volts
L1—5 mH inductor
S1—miniature SPST momentary pushbutton
S2—miniature SPST momentary pushbutton (optional)
T1—9-volt, 150-mA, PC-mount transformer

Note: The following kits and components are available from Dick Smith Electronics, P. O. Box 8021, Redwood City, CA 94063: Complete receiver including all parts, case, and mounting hardware, no. K-3428, $32.00; transmitter including all parts, case, but less battery, no. K-3429, $7.95; transmitter battery, no. S-3335, $1.19; receiver case, no. H-2503, $5.95; transmitter case, no. H-2497, $1.95; $2.50; BPW-50 IR photodiode, no. Z-1956, $2.50; µPC1373 IR photodiode preamplifier, no. KZ-6174, $2.50; twelve-volt relay, no. S-7200, $4.95; nine-volt transformer, no. M-2840, $2.50. All orders must add $1.50 plus 5% of total price for shipping and handling. California residents must add 6.5% sales tax. Orders outside the U. S. must be in U. S. funds and add 15% of total price.

HUMIDITY MONITOR

Don't let static zap your costly electronic gear! This electronic humidity monitor lets you spot potentially dangerous conditions.

MARK C. WORLEY

IF YOU'RE LIKE MANY PEOPLE, YOU TEND to downplay—or simply ignore—the importance of humidity. But you shouldn't! The reason is that, after temperature, humidity is the most important environmental condition that affects our comfort level. We're comfortable when the humidity is low in the summer, but that same low humidity can make us feel uncomfortably cool in the winter.

Perhaps more important to the readers of **Radio-Electronics** is the fact that humidity—or the lack of it—can drastically affect the operation of the electronic devices we love so well: computers, TV's, VCR's, stereos, etc. Proper humidity control in the winter months can reduce the static buildup that is so often detrimental to the operation of electronic equipment. For example, a rule of thumb states that you should be careful when the humidity drops below about 50% as the temperature drops below about 70°. You certainly wouldn't want to handle any CMOS IC's in those conditions!

In order to help you bring your humidity problems under control, we will discuss what humidity is, some of its effects, and several historical means of measuring it. Then we'll show you how to build a modern, electronic humidity monitor that features 5% accuracy for about $50.

What is humidity?

Humidity is usually specified as percent *R*elative *H*umidity, or RH, for short. Relative humidity is not a *measurement* of the amount of water vapor in the air. Rather, RH is the ratio of the amount of water vapor in the air to the maximum amount of vapor that air can hold. That maximum varies primarily with temperature, although barometric pressure affects it to a lesser degree.

For example, let's assume that a given volume of air at a given temperature can hold one ounce of water vapor. If that air contains half an ounce of water, its relative humidity is 50%. If that same volume of air were cooled, it might be able to hold a maximum of only $^{6}/_{10}$ an ounce of water. So if that air still contained half an ounce of water, the relative humidity would now be $0.5 \div 0.6$, or 83.3%.

On a hot day the relative humidity governs our comfort primarily because it affects the efficiency of our natural cooling system—our sweat glands. If the humidity is high, sweat can't evaporate as readily. That's why a hot, dry day is more comfortable than a warm, humid day. Various "comfort zone" charts have been developed that show which combinations of temperature and humidity are the most comfortable.

The effects of humidity are evident all around us. For example, dew is caused by cooling of the air during the night until it saturates (reaches 100% RH), and it then releases excess moisture onto any cool surface. The temperature at which that saturation occurs is called the *dew point*.

Here's another common effect of humidity: iced drinks that "sweat" on a hot day. That "sweating" is really caused as follows. The outer surface of the glass is cooled by the icy contents of the glass. That surface in turn cools the surrounding air.

When that air reaches the dew point temperature, it releases some of its excess moisture onto the surface of the glass. So in reality that "sweating" is not perspiration from the glass, but condensation from the atmosphere. Hence the reason cold drinks don't "sweat" as much in dry climates as they do in humid ones is that there's very little water in the air to condense on the glass.

Measuring humidity

Temperature is easy to measure using a simple thermometer, or any of a number of solid-state devices. Humidity, on the other hand, is probably the most difficult environmental condition to measure. The search for an accurate, dependable means of measuring humidity has occupied scientists for centuries. For example, Leonardo Da Vinci noticed in 1550 that a ball of wool weighed more on a rainy day than on a dry day. Ever since then scientists have been refining ways of measuring RH precisely. For example, methods using various organic substances, electro-optical sensors, resistive sensors, and variable-capacitance sensors have been developed. Each method has unique advantages and disadvantages.

Organic sensors like human hair, animal hair, and animal membranes have been in use the longest, and are still in use today. An organic tissue absorbs moisture readily, and, as it does, it will stretch more easily. That stretching can be measured, and that provides an indirect indication of RH. As you might suspect, the primary disadvantage of organic sensors is their tendency to age rapidly, and that requires frequent re-calibration.

Relative humidity can also be calculated by measuring the dew point. The dew-point method is highly accurate, but cumbersome, because of the cleanliness, and the complex, precise circuitry that are required. A mirrored surface is monitored as it cools until moisture begins to form on it. The temperature at which moisture is detected is the dew point, and that is dependent upon relative humidity. The dew-point method is most suitable for laboratory work.

Resistive sensors have their problems, too. The resistance of that sort of sensor usually ranges from the hundred of thousands of ohms to the tens of megohms. That high resistance, plus the non-linear response curves of those sensors, makes them difficult to work with. In addition, they can be damaged by direct contact with moisture, by common airborne contaminants, or by simple DC voltages. Most sensors require an AC excitation voltage, because even a small DC voltage can cause chemical migration within the sensor, and that usually ruins it.

Another humidity sensor is based on variations in capacitance. Sensors of that type weren't commonly used in the past because of their high cost—typically $100 or more apiece—and because they can be difficult to use due to their small variation in capacitance. However, the sensor shown in Fig. 1, developed by the N. V. Philips Company, and sold in this country by Mepco/Electra (Columbia Road, Morristown, NJ 07869), is inexpensive and easy to work with.

The sensor

Philips' humidity sensor is a capacitor formed from a dime-sized piece of plastic film that is coated on both sides with a very thin layer of gold. Because the dielectric constant of that film varies with changes in RH, so does the sensor's capacitance. On each side of the film the gold functions as one plate of a capacitor; it also provides the electrical contact for the sensor-housing's spring-contact leads. The sensor measures about 0.6" in diameter, and 0.9" high. We list some of the specifications of Philips' sensor in Table 1. For more information, see Mepco's Technical Information Brochure 063, their Technical Note 134, and the data sheet that comes with the sensor.

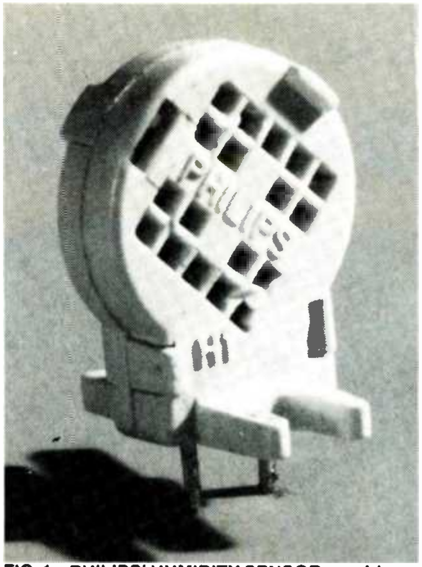


FIG. 1—PHILIPS' HUMIDITY SENSOR provides a 45-pF change in capacitance over the 0–100% humidity range.

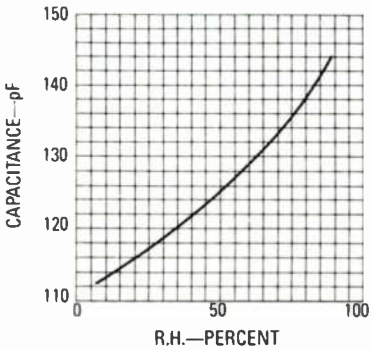


FIG. 2—THE SENSOR'S CAPACITANCE and the relative humidity are related exponentially.

The curve in Fig. 2 shows how the sensor's capacitance varies with humidity. By extrapolating a little we see that capacitance varies from about 115 pF at 0.0% RH to about 160 pF at 100% RH. In other words, there is a change in capacitance of 45 pF over the entire RH range. So, in order to measure RH, all we need is a circuit that translates that 45 pF variation in capacitance to a properly scaled variation in voltage.

But before we discuss the details of circuit operation, there are a few other things you should know that affect the accuracy obtainable from our humidity monitor. First, the sensor has a drift of 0.1% per degree Celsius, which translates to an inaccuracy of 1% for a 10°C change in temperature. So, over a range of 40°C, accuracy will drop to about 4%. Given proper calibration, our humidity monitor should be accurate, therefore, to better than 5% RH over a wide temperature range. Just compare that to the typical 25% accuracy—or worse—of the dial-type humidity indicator included with many wall- and desk-top thermometer-barometer-humidity monitors! You should also be aware that the capacitance of the sensor is somewhat dependent upon the frequency applied to it, but to obtain the accuracy we're interested in, we can ignore that variation.

Circuit operation

If we were simply to build an oscillator whose frequency varied in response to changes in the sensor's capacitance, we could measure relative humidity, but we'd have an offset problem, because 0.0% RH corresponds to 115 pF, not 0.0 pF. In other words, we'd have some output even at 0.0% relative humidity. So we use *two* oscillators in our circuit, and measure the *difference* between their outputs. That allows us to obtain an output of 1.00 volt for 100% RH.

Our circuit is a modified version of one supplied by Philips. In their circuit, one 4001 CMOS quad-NOR package was used to build the two oscillators, and the gates in a second 4001 were connected in parallel to provide extra drive for the rectifier/filter circuit. We decided to use 7555's for the oscillators because they're only slightly more expensive, but much more

TABLE 1—SENSOR SPECIFICATIONS

Parameter	Value
Humidity range	10–90% RH
Temperature range	0–85°C
Capacitance (25°C, 43% RH, 100 kHz)	122 pF, ±15%
Frequency range	1–1000 kHz
Temperature dependence	0.1% RH/°C
Response time (max)*	
10–43% RH	3 minutes
43–90% RH	5 minutes
Typical hysteresis	3%
Maximum voltage	15 volts

*To 90% of final value, @ 25°C, in circulating air

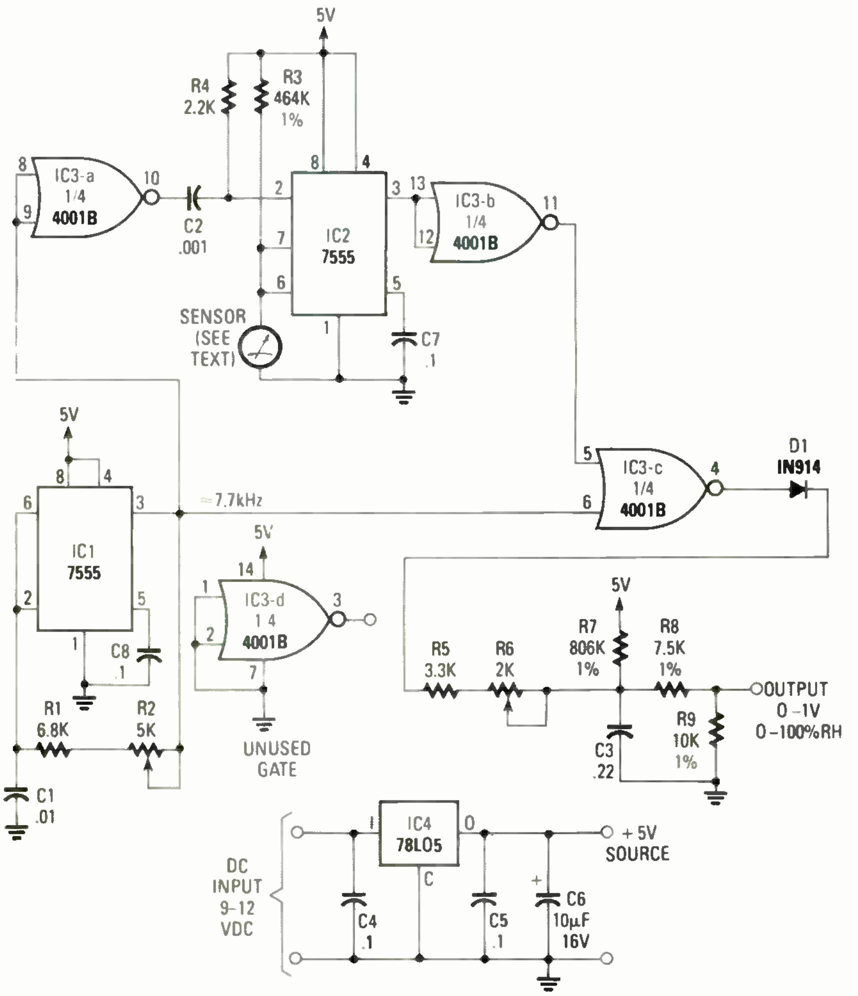


FIG. 3—THE HUMIDITY MONITOR CIRCUIT uses CMOS 555's to keep current drain low.

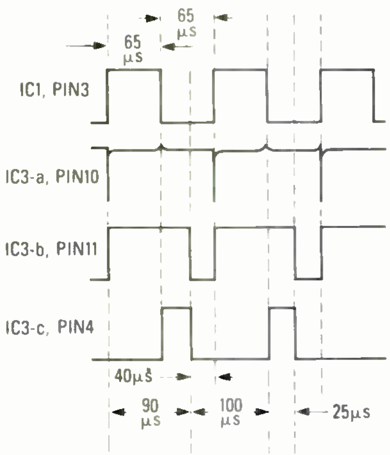


FIG. 4—TIMING RELATIONSHIPS of various points in the humidity monitor's circuit are shown here.

predictable (and repeatable) than oscillators made from CMOS gates. Also, we found that it was unnecessary to use paralleled gates to drive the metering circuit.

As you can see from the schematic in Fig. 3, our humidity monitor is composed of three CMOS IC's and a low-power voltage regulator. Total current drain is only about 5 mA, so battery operation is entirely feasible. The circuit consists of two oscillators, a few NOR gates, and a detector/filter circuit that helps linearize the output.

A CMOS 7555 is used for IC1, a 7-kHz astable oscillator. A CMOS 7555 is also used for IC2, a one-shot whose pulse width is determined by R3 and the capacitance of the sensor. The master oscillator (IC1) drives IC3-a, which provides the trigger pulse that drives IC2. The relationship of those two signals, and the others to be discussed below, is shown in the timing diagram in Fig. 4.

The output of IC2 is inverted by IC3-b and combined with the master-oscillator signal by IC3-c, which passes only the difference between the two signals to the filter/detector circuit that follows. Trimmer potentiometer R2 is provided to null the circuit out at the low end of the RH scale. On a dual-trace scope the null condition appears as equal-phase, equal-width pulses at pins 5 and 6 of IC3-c. With inputs of that sort, IC3-c gives no output.

The detector circuit is composed of diode D1, resistors R5–R9, and capacitor C3. The pulses from IC3-c are rectified and filtered into a DC voltage that is proportional to relative humidity. Full-scale meter adjustment is provided by R6, and R8 and R9 function as a voltage divider that scales the output to exactly one volt at 100% RH.

Since the sensor's capacitance is exponentially related to RH, something is needed to increase the linearity of the circuit. That something is provided by R7, which supplies extra charging current to C3, which would normally be fed only by the detector. Also, R8 and R9 discharge C3 to further increase linearity. The only drawback to our scheme is that, due to the voltage-divider effect of R7–R9, the out-

PARTS LIST

All resistors ¼-watt, 5%, metal film (not carbon composition!) unless otherwise noted.

R1—6800 ohms
R2—5000 ohms, linear potentiometer, PC mount
R3—464,000 ohms, 1%, ¼-watt
R4—2200 ohms
R5—3300 ohms
R6—2000 ohms, linear potentiometer, PC mount
R7—806,000 ohms, 1%, ¼-watt
R8—7500 ohms, 1%, ¼-watt
R9—10,000 ohms, 1%, ¼-watt

Capacitors

C1—0.01 µF, 10%, mylar or polycarbonate
C2—0.001 µF, 10%, mylar or polycarbonate
C3—0.22 µF, 10%, mylar or polycarbonate
C4, C5, C7, C8—0.1 µF, ceramic, monolithic, or disc
C6—10 µF, 16 volts, electrolytic or tantalum, radial leads

Semiconductors

IC1, IC2—7555 CMOS 555 timer
IC3—4001B, CMOS quad dual-input NOR gate
IC4—78L05, 5-volt, 100-mA voltage regulator
D1—1N914, 1N4148, or equivalent

Other components

M1—50 µA
S1—SPST toggle or momentary switch
Sensor—Mepco #2322-691-90003
Sensor socket—Molex part #10-18-2031
Portable case—Radio Shack #270-1751
Outdoor case—Keystone part #677 (set of #666 & #685)

Note: The following are available from Mark Worley, 10614-B Golden Quail Drive, Austin, TX 78758; Screened, drilled and plated PC board, $7.00; Sensor $15.00 for 1 or $25.00 for 2; Calibration capacitors (115 pF and 160 pF, 1% mica), $2.00 per set; Kit of IC's, sensor, sensor socket, PC board, resistors, and capacitors, $40.00 (calibration capacitors, meter, enclosure, & hardware not included). Data sheets and op notes for sensor, $4 postpaid. Add 10% for shipping, $3.00 maximum. Allow up to 30 days for delivery. Send cash or check only.

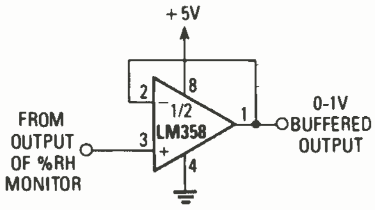


FIG. 5—AN OP-AMP VOLTAGE FOLLOWER may be used to buffer the output of the humidity monitor.

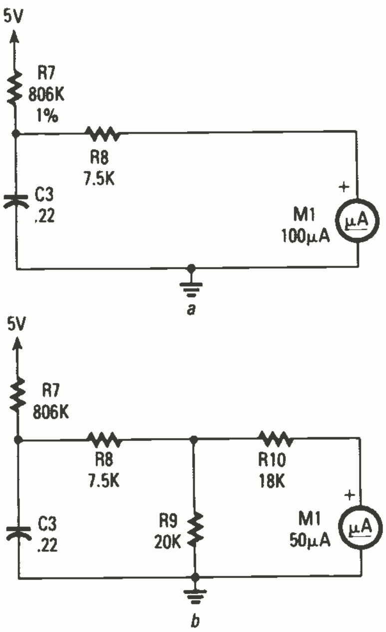


FIG. 6—METERING CIRCUITS for the humidity monitor. Use the circuit shown at *a* with a 100-μA meter, and the one at *b* with a 50-μA meter.

put cannot fall below 60 mV, which corresponds to 6% RH. So, our monitor can read no lower than 6% RH.

For best accuracy, the output should be monitored with a meter having an input impedance of at least one megohm. Alternatively, the output could be buffered to drive an analog meter or other low-impedance load. The simple op-amp voltage-follower circuit shown in Fig. 5 could be powered by the same (battery) supply that powers the remainder of the circuit. Or you could, if desired, substitute a pre-assembled digital LED- or LCD-meter module.

Another alternative would be to use a 100-μA moving-coil meter as an indicator. Since a 100-μA meter with a full-scale reading of one volt has a resistance of 10K, it could replace R9 in the circuit, as shown in Fig. 6-*a*. But since a 100-μA meter is slightly difficult to obtain, we used a 50-μA meter with the voltage divider shown in Fig. 6-*b* for our prototype.

Current drain

The 78L05 low-power voltage regulator adds about 4 mA of current drain to the circuit, which would otherwise consume only about 1.5 mA. That 4 mA is the regulator's required operating current, so it can't be eliminated (unless you can obtain one of National's new micro-power voltage regulators). A Zener diode would not alleviate the current-drain problem, since it would require even more operating current. A Zener diode would also have poorer regulation, which could affect accuracy. With no voltage regulator at all, the pulse height from IC3-c would vary with battery voltage, so accuracy would be affected.

For portable or occasional use, a 9-volt battery is the ideal power source, since current drain is low. Alternatively, power could be supplied by an inexpensive wall-mount transformer with an output of 7.5- to 12-volts DC. For permanent outdoor installation, mount the power supply inside the house, not out in the weather.

Construction

Our humidity monitor can be used in a portable mode both indoors and outdoors. However, for permanent outdoor installation more rugged construction techniques will have to be used. We'll present plans for both portable and permanent units, although we'll stress construction of the portable unit.

The circuit should be built on a PC board to minimize stray capacitance that could affect IC1's output frequency and IC2's pulse width. You can purchase a PC board from the source listed in the Parts List, or you can etch and drill your own using the foil patterns shown in the "PC Service" section of this magazine. It's not recommended, but if you assemble the circuit on perf board, use the kind that has a solder pad around every hole (such as OK Industry's #A-PC-02 prototyping board). You may have trouble experimenting with our circuit on a solderless breadboard because that type of breadboard has a large amount of distributed capacitance and a ground plane that can also affect circuit operation.

Use only high-quality, low-temperature-coefficient components to limit the effects of temperature on the circuit's accuracy. Capacitors C1 and C2 should be polystyrene or polycarbonate types. It might be worthwhile experimenting with a positive-temperature-coefficient capacitor for C1 to offset some of the sensor's temperature drift, especially if the monitor will be used outdoors. The resistors should be metal- or carbon-film types; carbon composition resistors should not be used in our circuit because their values vary widely with temperature and humidity.

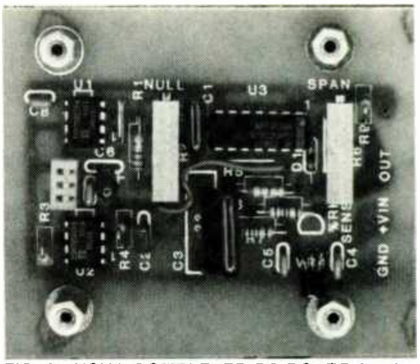


FIG. 8—YOUR COMPLETED PC BOARD for the humidity monitor should appear as shown here. Interconnecting wires attach to the bottom of the board.

When you have a suitable board, use the parts-placement diagram in Fig. 7 and the photo in Fig. 8 to mount and solder all components. Don't use IC sockets since they can contribute to stray capacitance. Solder the 3-pin Molex socket to the board vertically (as shown in the photo) if you want to mount your sensor as it is in our prototype. Also, for proper vertical clearance you may find it necessary to use a small tantalum capacitor for C6, or to mount that capacitor to the foil side of the PC board.

After mounting all components, check your work carefully, looking for solder bridges between adjacent pads, pins and traces. If the board is OK, remove all flux from it. Be careful to keep any solvent—particularly acetone—away from the sensor. Use isopropyl alcohol to remove finger oils, and avoid touching cleaned surfaces.

Use a pair of clipped-off resistor leads to extend the lengths of the sensor's leads. Carefully solder the wires to the sensor, and make sure you don't damage the sensor from too much heat! Then clip the leads to an overall length of ¼ inch. They will project through the case and into the Molex socket after final assembly.

Now let's turn to mechanical construction. First we'll discuss the portable unit. Drill a mounting hole in each corner

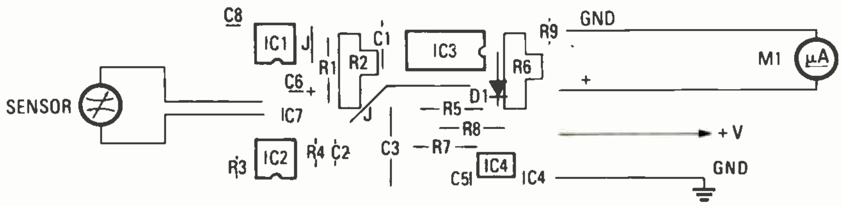


FIG. 7—PARTS-PLACEMENT DIAGRAM reveals the compact size of the humidity monitor.

of the board, and use those holes to mark the locations of the screw holes in the case. Also, drill four holes for the sensor: two for the leads, and two for the mounting tabs. Use an eighth-inch bit (or larger) for the sensor leads to minimize capacitive coupling to the case, as well as to eliminate the possibility of a short. Allow for a little offset in the position of the sensor due to the construction of the Molex socket.

The meter used in our prototype has a resistance of about 2K, so we added an 18K resistor in series with the meter to give it a total resistance of 20K. Then R9 was changed to a 20K resistor, so that the combination of R9, the meter, and R10 would be 10K. That combination gives the meter a full-scale range of one volt.

If you use a 100 µA meter, pad its resistance to 10K, if necessary. Then remove R9, and use the meter in place of that resistor. If you decide to use a digital meter, you can leave R9 at 10K, since most digital meters have at least 10 megohms input impedance, and the parallel combination of R9 and the DVM will not affect accuracy.

Mounting the sensor at the "rear" of the case might reduce the sensor's ability to respond to current humidity conditions, especially if the monitor is pushed back on a shelf. However, mounting the sensor in that way reduces the possibility that it will be damaged. But feel free to experiment with your own case and mounting methods. We bent a ½-inch piece of thin steel strapping into a "U" shape with legs. Holes were drilled through the legs and through the case on either side of the sensor. Then the "U" was bolted to those holes to prevent mechanical damage to the sensor.

Finish assembling the case by installing the power switch, battery holder, and four ¼-inch standoffs for the PC board. If necessary, carefully remove the face plate of the meter and use rub-on letters to re-label the meter's scale. Assuming you're using a 50-µA meter, wire the case-mounted components as shown in Fig. 9. If you're using a different metering circuit, substitute the appropriate resistive network. Loose wires and components can move around and cause the outputs of IC1 and IC2 to vary, so mount all components securely, and keep all leads short.

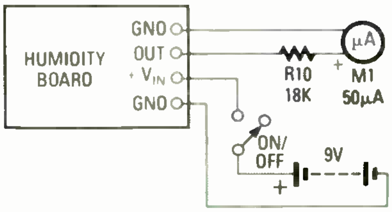


FIG. 9—IF YOU USE A 50-µA METER with the humidity monitor, it should be wired as shown here.

To complete assembly of the portable unit, mount the board to the case. Then insert the sensor's leads through the case and mount the sensor to the case with two sheet metal screws. Be careful not to crack the sensor by over-tightening those screws.

Building the outdoor monitor

For permanent outdoor use, the sensor must be covered to protect it from direct rain and sunlight. A small louvered or screened box about ten inches on a side should work. Just make sure that air can circulate freely through the enclosure to reach the sensor. Also, avoid placing the assembly in vegetation, near a sprinkler, or in any other location that might tend to exaggerate the actual humidity. A hundred feet of 22-gauge wire between a remotely-mounted sensor and an indoor power supply and display meter should not affect accuracy.

To install the monitor outdoors permanently, the circuit will have to be mounted in a watertight enclosure. We'll discuss how to do that using the Keystone enclosure specified in the Parts List.

First, trim the PC board to fit the case. Then cut four two-inch lengths of 18-gauge wire and insert them into the holes at the end of the board. Bend the leads so that at least ¼-inch of the wire lies flat against the copper foil, and then solder the leads. The ¼-inch of contact helps strengthen the support for the board. Slide the free ends of the wires into the octal base of the case. Carefully bend the leads so that the end of the PC board rests against the base. Then clip the leads flush with the end of the plug's pins, and solder the wires inside the hollow pins. The octal plug won't fit into its socket if solder leaks through to the outside of the pins, so be careful.

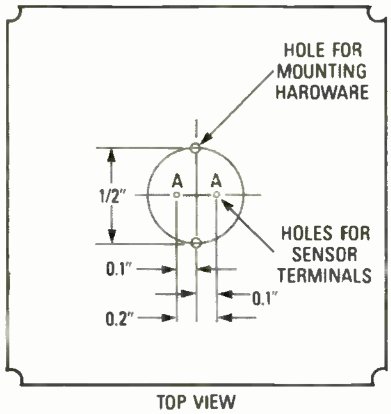


FIG. 10—OUTDOOR INSTALLATION of the humidity monitor requires a watertight case; drill holes for the sensor as shown here.

Refer to Fig. 10 to drill the mounting holes for the sensor in the top of the case, and to Fig. 11 to drill the holes in the side of the case that allow access to trimmer potentiometers R2 and R6. Those holes must be located precisely as shown to allow proper assembly and adjustment. If you use a small metal punch for the access holes in the side, you may be able to re-insert the punched-out pieces in the holes after calibration; otherwise fill the holes with epoxy, or cover them with electrical tape.

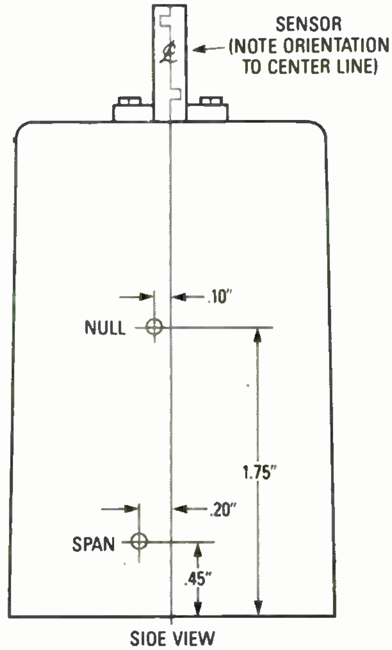


FIG. 11—TWO HOLES MUST BE DRILLED in the side of the waterproof case to allow final calibration.

Bend the leads of the Molex connector 90 degrees before mounting it flush against the PC board. Then solder a scrap of wire across the socket to hold it in place firmly; two holes have been provided in the PC board for that support wire. The sensor's leads will have to be extended to a length of ⅝ inch.

To complete assembly, attach the sensor to the case with two sheet metal screws. A thin rubber gasket placed between the sensor and the case will provide additional weatherproofing. Carefully insert the board and the base assembly into the case so that the Molex connector mates with the sensor's extensions. Use four screws to hold the case and the octal base together. The two holes in the side of the case should line up with R2 and R6 so that those potentiometers can be adjusted easily with a small screwdriver.

Final check-out

The check-out is the same for both the portable and the permanent versions of our humidity monitor. Before powering up, carefully check the board once more to make sure that all components have been installed correctly, and that there are no solder bridges between traces, etc. Then plug the sensor into its socket and apply power. You should be able to measure some voltage across R9 (in other words, M1, if installed, should deflect): that voltage should rise if you breathe on the sensor.

If you get no output, re-check your work, and verify that supply voltage (five volts) appears at pin 8 of IC1, pin 8 of IC2, and at pin 14 of IC3. If that voltage is present, use an oscilloscope to verify the presence of the waveforms shown in Fig. 4. After the board is debugged, allow it to cool down from the heat of soldering before doing the final calibration. Also, isolate the sensor from hand and breath moisture until it stabilizes to ambient humidity—about 5 minutes should do it.

Calibration

For the first step of calibration we'll assume that the sensor's output exactly matches the curve shown in Fig. 2. Doing that allows us to substitute 1% silver-mica capacitors for the sensor. Insert a 115-pF capacitor into the sensor's socket and adjust R2 for a reading of 6% RH (60 mV). Then replace that capacitor with a 160-pF unit and adjust R6 for a reading of 100% RH (1.00 volt).

After assembling the case, you will need to re-adjust R2 so that the output agrees with a secondary humidity standard. That adjustment alters IC1's pulse-width to correspond to the sensor you're using. Remember, the Philips sensors have a tolerance of ±15% at 43% RH. This means that, although there will still be a 45-pF change in capacitance over the entire 0–100% range of RH, the high and and low values may be shifted above or below the nominal values. It is R2 that provides compensation for that shift.

Absolute calibration standards

Finding a humidity standard can be difficult, but here are a few ideas that may be useful. The most common method of measuring humidity accurately is with a sling psychrometer. You may be able to borrow one from a science or chemistry lab at a local high-school or college. The sling psychrometer has both dry- and wet-bulb thermometers. The wet-bulb unit has a wick on its bulb that is moistened with distilled water. When the psychrometer is whirled in a circle, the evaporation of the wick cools the thermometer's bulb. The amount it cools depends on the amount of water that evaporates, and that is governed by the amount of moisture in the air—the relative humidity.

The dry-bulb thermometer is unaffected by that procedure since it's not moistened: it simply indicates the temperature of the ambient air. With every psychrometer comes a chart that allows you to determine RH from the readings on the two thermometers.

The accuracy of the sling psychrometer method depends on the accuracy of the two thermometers, the accuracy with which they're read, the cleanliness of the wick and the water, and also upon a sufficient quantity of air blowing across the wick. Small sling psychrometers with one degree increments and short thermometers have an accuracy of only 10%, or worse.

Saturated salt solutions offer better accuracy, but they are more difficult to use because the sensor has to be placed as close as possible to the solution without touching it, and the calibration process must occur inside an airtight container. That can make circuit adjustment awkward. Anyway, the solution maintains an equilibrium of humidity within the sealed container as long as that solution remains saturated. Both salt and water must be pure for best accuracy. We list some commonly-used solutions, and the humidities you can obtain with them, in Table 2.

Caution: Those solutions are poisonous, so handle and store them with care, and keep them out of the reach of children and pets. If you use the lithium chloride solution, don't allow it to fall below a temperature of 18°C (64°F), since the humidity reference of the solution will be permanently altered. Whichever salt you use, stir in crystals a little bit at a time until precipitates begin collecting on the bottom of your container. When you're sure no more salt will dissolve, put the solution and your circuit board in an airtight container, and adjust R2 so that the meter agrees with the value in Table 2.

TABLE 2—SATURATED SALT SOLUTIONS

Salt	% RH @ 68°F	% RH @ 77°F
Lithium Chloride Monohydrate	11.3	11.2
Magnesium Chloride Hexahydrate	33.1	32.8
Magnesium Nitrate	54.4	52.9
Sodium Chloride	75.5	75.3
Potassium Chloride	85.1	84.3
Potassium Sulphate	97.6	97.3

One problem with the above calibration procedure should be obvious—how does one make the adjustments while the board is within the air-tight container? There are two possibilities. One is to make the adjustment outside the container, then place the board inside to see the result. Repeat as needed until the meter reading agrees with the value in Table 2. A more sensible solution would be to mount only the sensor in the container so that R2 can be adjusted from outside.

If those methods of calibration are impractical for you, you might try tuning in a local weather broadcast on radio or TV, or you could call the National Weather Service in your area. To do the final calibration, whatever standard you have chosen, apply power and then adjust R2 so that the value indicated by the meter agrees with your standard. Construction is now complete.

Final thoughts

Whether or not you actually built our humidity monitor, we hope you learned something about what humidity is and about ways of measuring it. Like many subjects, there is a great deal more that could be said about humidity; we encourage you to do some investigating on your own. In a similar vein, our circuit was not intended to be used as the basis of a precision instrument, but we hope you'll find it fun to build as well as useful.

As you know, indoor humidity drops drastically in the winter. The reason is that cold, dry outside air is further dried by most indoor heating systems. (To be more accurate, hot air can hold more moisture than cool air, so the RH drops as the temperature rises. You may find it interesting to know that office buildings are often built these days with humidity controllers in addition to the systems that control their heating, ventilation, and air-conditioning (HVAC) systems.

You can use our humidity monitor to help maintain humidity levels at your home or office at a comfortable (and safe!) level. Humidity control can help prevent respiratory problems, and it can prolong the life of valuable paintings, books, and electronic devices.

For indoor use, avoid placing the humidity monitor near air-conditioning or heating vents; also, keep the monitor far away from any large potted plants since they can affect accuracy. For desktop use, keep the sensor away from a hot work-light, as heat can also affect the humidity reading.

An RH of less than 20% can easily occur during the winter. And with such low humidity, a large quantity of static electricity can build up, since the conductive moisture usually present in the air isn't available to provide a discharge path for that energy.

Making sparks fly by touching your spouse's nose or a metal surface may be fun, but doing that to your computer (or just about any electronic device) could prove fatal for the machine. Similarly, you're much more likely to damage CMOS and other components while building projects like our humidity monitor. So, an RH of about 50% is low enough for you to be comfortable, and high enough for your electronics to be safe. **R-E**

Capacitor Leakage Tester

GARY McCLELLAN

Find the leaky capacitors that many testers miss with this easy-to-build leakage checker. You can use it to test cables, appliance insulation, and high-voltage diodes, too!

THOSE NEW DIGITAL CAPACITANCE TESTers make capacitor checking quick and easy, but they have shortcomings. For instance, does the following sound familiar to you?

You are troubleshooting a piece of equipment and replace some defective capacitors with units from the junk box. After hours of additional troubleshooting you discover that those replacement capacitors are no good after all, even though they checked out OK on your tester. That's because they are leaky, and your meter is one of the many that has no leakage-test function. That "missing feature" wound up costing you much time and aggravation.

Or perhaps you just bought some electrolytic capacitors from your dealer, installed them, and watched as the power-supply fuse blew. You later find that the cause was those "new" capacitors: they had become leaky after sitting on your dealer's shelf for the better part of a decade. If you had only known, those capacitors could have been rejuvinated with a shot of current from the proper source. Instead, you have a blown fuse and some fried capacitors.

Assuming it does everything else well, don't trash your capacitance tester just because it doesn't have a leakage-test function. Instead, supplement it with the leakage tester described here. Our tester checks the all-important leakage parameter quickly and easily, weeding out defective capacitors that otherwise test good. It can also brings those elderly "new" capacitors back to life fast.

Besides checking capacitor leakage, the circuit has many other uses on the bench and in the field. For example, use it to test insulation resistances on power tools and appliances. If you find just one tool or appliance with a dangerous fault before it finds you, you'll be very glad you took the time to build and use the circuit. You can also test suspected lossy cables, as well as high-voltage diodes, rectifiers, neon lamps, and other high-voltage components that are often difficult to troubleshoot with conventional DMM's.

And in a pinch the circuit can serve as a regulated power supply. The output voltage spans 3 to 100 volts, which may make the project useful for temporarily powering devices drawing under 10 mA or so.

The circuit is easy to build and is fairly inexpensive, too. A small PC board holds the active components, including two IC's, three transistors, and some diodes, while the remaining switches and a meter mount on the cabinet. Parts costs will run about $45.00 or so, depending upon how well you can shop or scrounge for them. The PC board, and a few harder-to-get components, are available from the source mentioned in the Parts List.

How it works

The project is basically a regulated DC power supply with a metering circuit to indicate leakage current. Refer to the block diagram in Fig. 1 for details.

There are several noteworthy features of which you should be aware. First, a novel power supply design permits the unit to charge test capacitors with a constant current source. That means they charge faster, saving you testing time, particularly for large capacitors. In addition, an analog meter is used for leakage-current measurements. That allows you to see the charging action and monitor the leakage current easier than with a digital meter. And analog meters are generally much cheaper than digital ones!

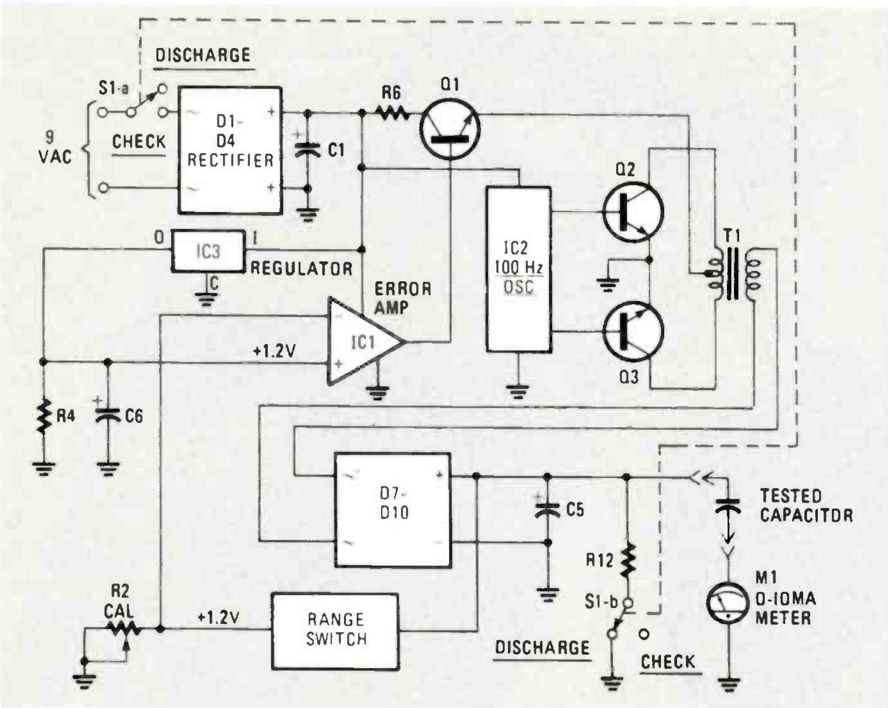


FIG. 1—THIS BLOCK DIAGRAM makes it easier to see how our little leakage tester works.

In operation, 9 volts from a plug-in transformer passes through switch S1-a and is rectified by diodes D1-D4. If field operation is required, it is possible to substitute a 12-volt battery for the plug-in transformer. The switch is a DPST unit that selects either power ON or capacitor DISCHARGE. From the rectifier, the output is filtered by capacitor C1, and is then used to power the rest of the circuitry.

Part of the power output is fed to IC3, a positive voltage regulator, which is used to provide a stable 1.2 volt reference for IC1. That ensures that the output voltage will be stable regardless of how much voltage is used to power the project.

Op-amp IC1 serves as an error amplifier. Its job is to ensure that the voltage applied to the capacitor under test is regulated. It does that by "sampling" the voltage at capacitor C5 through the range switch. The range switch is nothing more than a resistive attenuator network reducing the output voltage to about 1.2. The op-amp simply adjusts the power supply until its minus (inverting) input equals 1.2 volts. That regulates the output voltage.

Transistor Q1 serves as a control element for the rest of the power supply. Since the op-amp can't provide enough current to do the job directly, a Darlington power-transistor is used here to boost the current. Resistor R6 limits current to the rest of the circuitry, preventing transformer damage.

Moving on, the DC output from capacitor C1 powers IC2, which is a CMOS programmable one-shot wired as a 100-Hz oscillator with complimentary outputs. The outputs from IC2 alternately drive transistors Q2 and Q3, which serve as switches. They alternately switch each side of the transformer T1 winding to ground, generating current pulses.

Transformer T1 performs two purposes. First it steps up the current pulses so that they can be rectified. Second, under heavy load (as from a charging capacitor) it saturates, limiting the output current to the capacitor to about 20 mA. That forms a constant-current type power supply, which is especially effective in charging test capacitors.

The output from transformer T1 is rectified by diodes D7 to D10 and filtered by capacitor C5. From that point the DC output feeds back to the range switch, which is used along with op-amp IC1 to set the output voltage. The DC output also drives the test capacitor, which is connected to the project through binding posts.

Meter M1 is included in the minus leg of the test capacitor for monitoring the charging and discharging currents. Note that resistor R12 and switch S1-b are included to discharge the test capacitor when the power is turned off.

That takes care of the basics. Now turn to the schematic diagram of Fig. 2 for some details on the finer points of the circuitry. You should be able to identify the parts we just discussed on the schematic diagram.

First let's look at the error amplifier, IC1. Basically, that amplifier is set up as an inverting, gain-of-100 unit. Resistors R3 and R5 set the gain value. Although that practice is rather unusual for a power supply (R5 is usually not included), the reduced gain is necessary to permit stable operation when testing very large capacitors (say 15,000 µF). Diode D5 serves as

PARTS LIST

All resistors ¼-watt, 5%, unless otherwise noted
R1—8200 ohms
R2—5000 ohms, potentiometer, PC mount (Circuit Specialists 32JQ305 or equal)
R3—100,000 ohms
R4—270 ohms
R5—10 megohms
R6—10 ohms, 2 watts
R7—2200 ohms
R8—1 megohm
R9, R10—10,000 ohms
R11—18,200 ohms, ⅛-watt, 1%, metal-film
R12—100 ohms, 2 watts
R13—10 ohms
R14—68 ohms
R15—30,100 ohms, ⅛-watt, 1%, metal film
R16—40,200 ohms, ⅛-watt, 1%, metal film
R17—49,900 ohms, ⅛-watt, 1%, metal film
R18, R19—100,000 ohms, ⅛-watt, 1%, metal film
R20—150,000 ohms, ⅛-watt, 1%, metal film
R21, R22—249,000 ohms, ⅛-watt, 1%, metal film

Capacitors
C1—1000 µF, 16 volts, axial leads, electrolytic
C2, C6—0.1 µF, 50 volts, polyester
C3—0.0022 µF, 50 volts, polyester
C4—100 µF, 16 volts, radial leads, electrolytic
C5—2µF, 450 volts, axial leads, electrolytic

Semiconductors
IC1—LF356N op-amp (National)
IC2—4047 CMOS one-shot (RCA)
IC3—LM317LE adjustable voltage regulator (National)
Q1–Q3—TIP120 NPN Darlington (Radio Shack 276-2068 or equivalent)
D1–D4, D7–D12—1N4004 rectifier diodes, 400 PIV, 1 amp
D5—1N4148 silicon signal diode
D6—not used

Other components
M1—1-mA DC meter
S1—DPST miniature toggle switch
S2—12-position, 1-pole rotary switch (Radio Shack 275-1385 or equivalent)
S3—SPST normally-closed pushbutton switch
T1—117 volts/12.6 volts, 1.2 amps, center tapped (see text)
T2—117-volts/9 volts, 300 mA, wall-plug transformer

Miscellaneous: PC board, plastic case (Radio Shack 270-627 or equivalent), knob, hookup wire, 4-40 hardware, press-on decals, etc.

An etched and drilled PC board plus all 1% resistors listed above and voltage reference IC3 are available for $17.50 postpaid from: Mendakota Products, PO Box 2296, 1001 W. Imperial Hwy., La Habra, CA 90631. When ordering request part LC1 and enclose a check or money order for the appropriate amount. California residents include 6% sales tax. Sorry no COD's or credit card purchases.

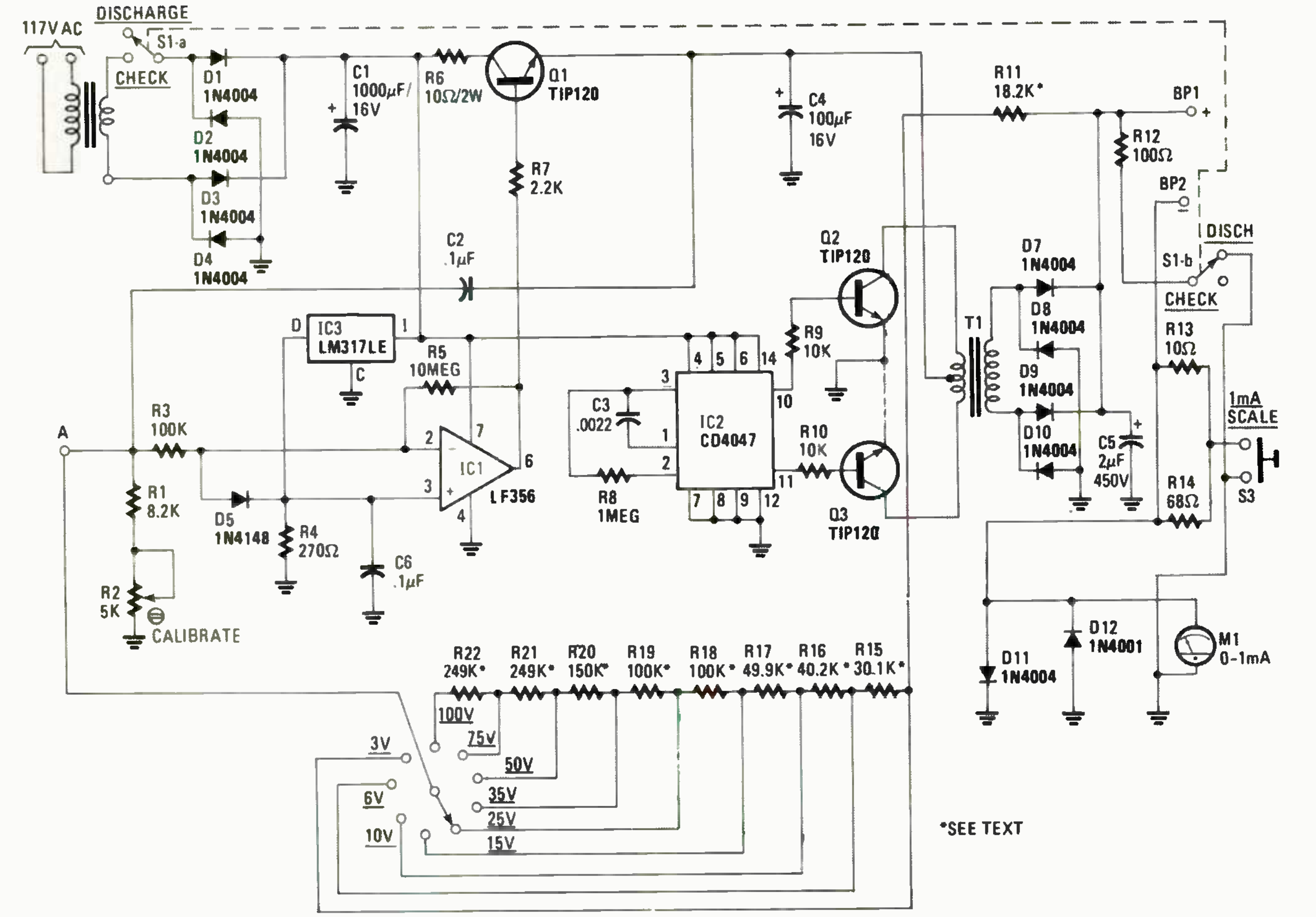


FIG. 2—THE CIRCUIT of our leakage tester is seen in greater detail in this schematic diagram.

overload protection, preventing excessive voltage from RANGE switch S2 from damaging IC1. That condition might occur if you were to switch rapidly from 100 volts to 3 volts. And finally, capacitor C2 provides some AC feedback, insuring stable operation over a wide range of capacitor loads.

Moving on, let's look at IC2. Resistor R8 and capacitor C3 set the operating frequency to 100 Hz. That frequency, while not critical, was chosen to prevent "beats" with the 60 Hz power line and permits increased output from transformer T1.

And finally, let's look at the metering circuit. Diodes D11 and D12 are included to protect the meter from harmful overloads, especially when a large capacitor is being discharged. A 10-mA current shunt consisting of resistors R13 and R14 is also included for measuring currents in non capacitor-testing applications. That shunt can be selected via pushbutton switch S3.

So much for the theory. Now why not get started building your project?

Construction

We'll describe assembly shortly, but first a few words about obtaining the parts. The circuit uses no exotic parts, and most should be available from Circuit Specialists (PO Box 3047, Scottsdale, AZ 85257), Radio-Shack, or your favorite electronics parts supplier. If you order the PC board from the supplier listed in the Parts List, you will also get the harder-to-find 1% resistors and voltage regulator. If you have trouble locating some items, try the suppliers that advertise in the back pages of this magazine. If after all of that you are still having difficulty locating a particular part, mail two first class stamps and a self addressed, stamped envelope to the PC-board supplier mentioned in the Parts List for assistance.

A word about T1: The board was designed to accommodate a transformer that was available from a parts supplier that had nationwide outlets. Since then, however, the transformer has been discontinued by that supplier. Fortunately, any 12.6-volt, 1.2-amp center-tapped transformer will do fine, although it likely will have to be mounted off the board.

Substitutions for other parts are also acceptable, providing they are equal or better in quality than the parts specified.

For the sake of both convenience and safety, you should use a PC board. If desired, you can buy one form the supplier listed in the Parts List, or else make one from the artwork provided in the PC-service section, found elsewhere in this magazine.

Once you have assembled the parts and obtained or made the PC board, you can start construction. Refer to Fig. 3 for details as we discuss assembly.

Start by placing the board in front of you with the foil side down. Then install a 100 µF capacitor at C4 along the top left-hand corner.

Continue by installing a wire jumper below C4. If you have been able to obtain a transformer that will fit on the board (see the preceding discussion), install it next. Otherwise, that transformer will have to be mounted off-the-board; in that event the wiring between the transformer and the board will be the among the last steps in the construction process.

Next, install 1N4004 diodes at D7 to D10 as shown. After that, install a 2-µF capacitor at C5, and a 100-ohm resistor at R12.

Finish up the top half of the board by installing a 18.2K (usually marked 1822F) resistor at R11, then a 10-ohm unit at R13. Also install a 68-ohm resistor at R14 and two 1N4004 diodes at D11 and D12.

Move back to the left edge of the board and continue assembly. Install TIP120

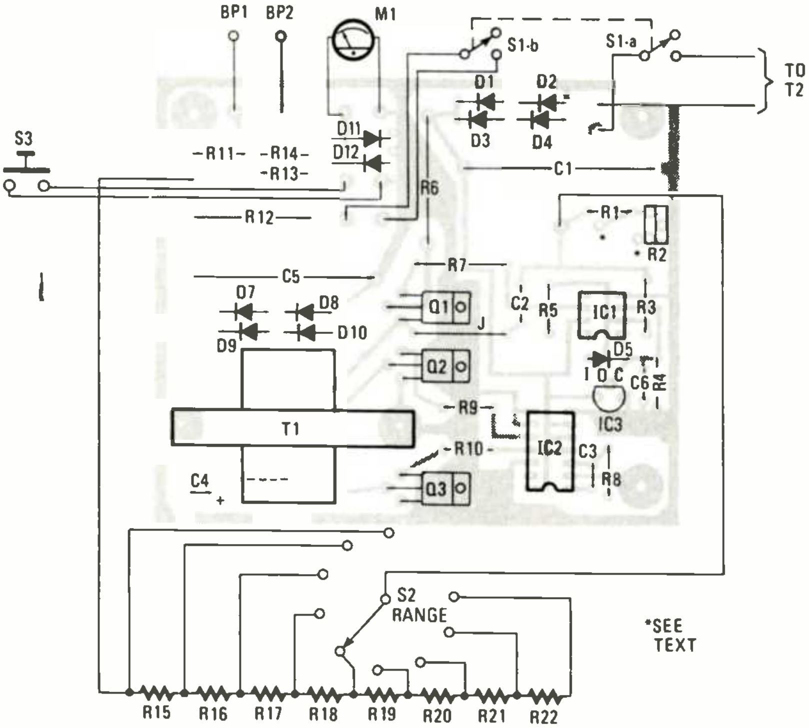


FIG. 3—FOR SAFETY, this project requires a PC board. Here we see the parts-placement diagram for the board shown in our PC Service section.

transistors at Q3 to Q1 first. Note that the leads are bent back 90 degrees, allowing the transistors to be mounted with the metal tabs flush against the board. Then install 10K resistors at R10 and R9.

Continue by cutting a short length of insulated wire and installing it between Q2 and Q1. Position the wire so it doesn't touch the transistors. Then install a 2.2K resistor at R7 and a 10-ohm unit at R6.

Install a 14-pin IC socket at IC2, then an 8-pin unit at IC1. Do not install those IC's until later. Next, install a 0.001-µF capacitor at C3 and a 1-megohm resistor at R8. After that, install a 270-ohm resistor at R4, a 0.1-µF capacitor at C6, and an LM317LE at IC3.

Finish the board by installing a 1N4148 diode at D5 and a 0.1-µF capacitor at C2. Then install a 10-megohm resistor at R5 and a 100K unit at R3. Next install a 5K potentiometer at R2. If the single-turn unit specified in the parts list is used, position the potentiometer with the adjustment screw next to the board edge. The additional pads have been provided around R2 so that a ¼-inch, multi-turn potentiometer (Radio-Shack 271-343 or equivalent) can be used if desired. After R2 is in place, install an 8.2K resistor at R1 and the 1000-µF capacitor at C1. Complete your work by installing 1N4004 diodes at D1 to D4.

Check your work carefully, especially diode and capacitor polarities before continuing. Fix any mistakes now, because they will be harder to correct later.

Refer to Fig. 4 to see the construction details for S2 and its associated resistors. Note that it is easier to wire the switch now than later when it is installed on the front panel. You might find assembly easier if you clamp the switch's shaft in a vise before starting work.

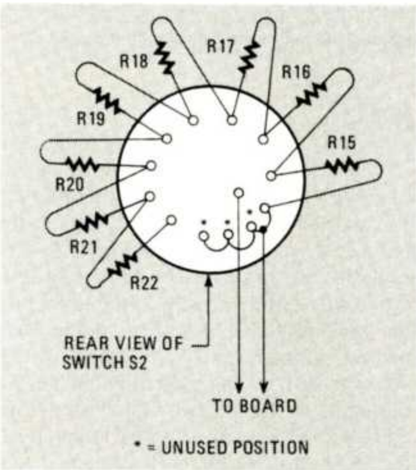


FIG. 4—RESISTORS R15–R22 are mounted on the rear of S2 as shown. Be sure to tie any unused switch positions to R15.

Wire the resistors on the back of switch S2 as shown. Note that most 1% resistors are marked in code; for instance, R15 would typically appear as "3012F."

When the resistors are wired in place, use a piece of bare wire to connect any unused terminals to R15 as shown. That prevents dangerously high voltages from appearing at the output terminals if S2 is set to an unused position. Finish the switch wiring by attaching 6-inch leads.

Set the board and switch aside for a moment and prepare the chassis. Note that the PC-board (and T1 if required) mounts inside of the chassis, while everything else goes on the front panel.

Place the board in the bottom of the box, against the top side. Drill three mounting holes for the board, plus a 1/4 inch hole in the top side for the power cord. Drill another 1/4 inch hole in the bottom side for access to pot R2. If T1 is mounted off-the-board, drill mounting holes as appropriate for the unit you are using.

Complete the mechanical work by installing the switches, binding posts, and meter on the front panel. Connect the switches to the appropriate points on the board.

When done, check your work carefully and correct any errors. Install the board in the box using 4-40 × 1-inch screws and nuts. Use a nut as a spacer between the board and box on each screw. If T1 is to be mounted off-the-board, install it in the chassis and wire the transformer to the appropriate points on the board. Feed the power cord (from T2) through the hole that has been drilled for it and connect the cord to the appropriate pads on the board.

Finish up the assembly by installing a CD4047 at IC2 and an LF356 at IC1.

Checkout

Now we get to try the project out. Plug transformer T2 into a nearby AC outlet. Then set S1 to the DISCHARGE position and likewise set S2 to the 100-VOLT position. Set your DMM to its 200-volt DC range and connect it to the binding posts (BP1 and BP2).

Flip S1 to the CHECK position and the DMM will read somewhere between 85 and 120 volts. If so, the project works and you can go to the calibration.

If you are having problems, disconnect the power and discharge capacitor C5 with a jumper wire. Then check over your wiring for errors. Remember—when troubleshooting, always discharge C5 after turning the power off; that can prevent a dangerous shock.

Calibration

Calibration is easy to perform. First set S1 to DISCHARGE, and then set S2 to the 100-VOLT range. Then set your DMM to its 200-volt DC range and connect it across the binding posts. Flip S1 to the CHECK position and adjust R2 until the DMM reads 100 volts.

To be on the safe side, you should check the output voltage for each position of S2; it should be within 2% of the panel value. If not, the 1% resistor associated with that position should be checked.

Using the project

Danger, high voltage! This project can provide a dangerous electrical shock if misused. Avoid a harmful shock by using

Continued on page 136

Walkman

AMPLIFIER

Build this versatile amplifier and get "home stereo" sound from your Walkman-*type cassette player or radio. It has many other applications, too!*

PORTABLE *WALKMAN*-TYPE STEREO CASsette players and radios are great for entertainment on the go, but sometimes it would be nice if they could be used to give full stereo sound—like a home hi-fi. Well, when used with the small, high-performance stereo amplifier described in this article, those units are capable of doing just that. In addition, thanks to the inclusion of a pair of preamplifier stages, the amplifier can be used with low-level inputs such as microphones, turntables, and electric guitars. It can even be wired up as a tiny PA system.

About the circuit

Figure 1 shows the schematic for the basic *Walkman* amplifier. It is designed around a National LM380 audio power amplifier IC. The gain of that low-cost IC is internally fixed so that it is not less than 34 dB (50 times). A unique input stage allows input signals to be referenced to ground. The output is automatically self centering to one half the supply voltage. The output is also short-circuit proof with internal thermal limiting.

With a power supply between 9 and 15 volts, and a minimum 8-ohm load, a heat sink is generally not required for the design shown. If you choose to build the circuit using the PC board shown in our PC Service section, a very small amount of heat sinking is provided by that board's design; the copper tracks act as thermal fins. Although that does not normally represent enough heat sinking if the IC is to be extended to its maximum capability, with this design and the limited parameters that the circuit operates within, that heat-dissipation scheme should prove sufficient. With a maximum supply of 15 volts and an 8-ohm load, the output is around 1.5-watts-per-channel. The input stage is usable with signals from 50-mV to 500-mV rms.

If the amplifier is to be used with a source other than a personal stereo, such as a phonograph or an electric guitar, some type of preamplifier is required. A suitable circuit is shown in Fig. 2. In that circuit, two 741 op-amps have been configured as input amplifiers. Their input stages have been referenced to a common point—half the supply voltage. That voltage is derived from a voltage divider made up of R1 and R2, two 2.2K resistors. The gain of each of the 741's has been fixed at 21 by the input resistors (R3, R4) and the feedback resistors (R9, R10). Input capacitors, C1 and C2, are used to filter out any DC component from the input signal.

With a power supply of 12 volts, the quiescent current drawn by the total system is 30 to 35 mA. Under driven conditions, the drain could increase to 300 mA or more.

Building the amplifier

While the circuit can be built using any construction technique, we recommend using a PC board. A suitable design is shown in our PC Service section (elsewhere in this magazine). The parts-placement diagram for that board is shown in Fig. 3. Note that the board has been designed to accommodate both the power amplifier of Fig. 1 and the pre-amplifer of Fig. 2. All inputs and outputs of both amplifier stages have been made accessible for maximum flexibility.

As with any project, the first step is to make sure that you have all of the parts on hand. One source for a complete kit of parts is given in the Parts List. Otherwise, you should be able to get most, if not all, of the parts from your favorite distributor.

Begin construction by installing all of the resistors, excluding the two potentiometers. Next, install the IC's. We realize that that order of construction is a bit unconventional, but because of the large size of the electrolytics that flank some of the IC's, it is easier to perform the steps in that sequence.

Once the IC's are in place, the capacitors should be installed. Be sure to note the polarity of the electrolytics and install them correctly.

The only connections left are the volume controls, R15 and R16, the input wiring, and the connection to the power supply. The potentiometers are panel-

*Adapted from a story that originally appeared in Dick Smith's "Fun ways into Electronics, Volume Three."

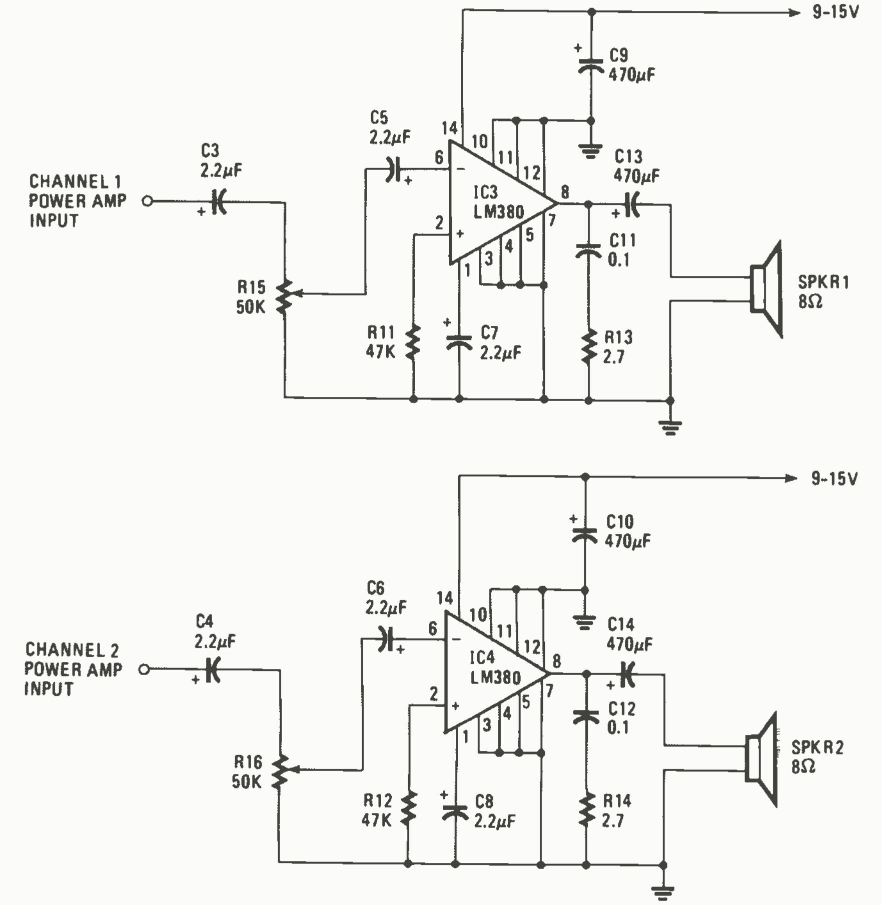


FIG. 1—THE *WALKMAN* AMPLIFIER. With this simple circuit you can use your personal stereo to drive standard 8-ohm speakers.

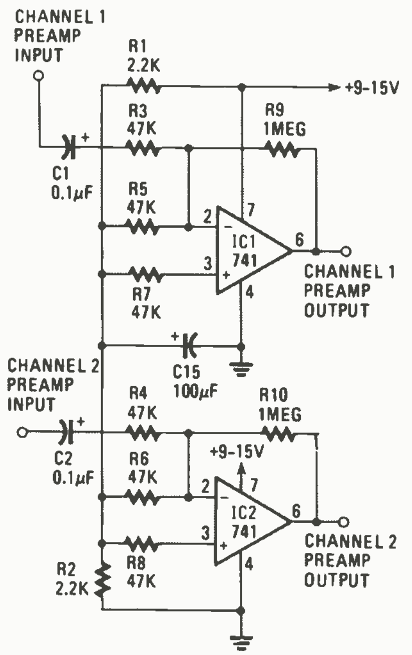


FIG. 2—THE PREAMP. If you wish to amplify low-level signals, such as the output of a turntable, the signal will first have to be fed to the preamp shown here.

mount units; they are mounted on the front panel of whatever case you house the circuit in, and they are connected to the board via jumpers.

The input wiring scheme is dictated by how you use the system. If you are using the amplifier with a *Walkman*-type stereo to drive a pair of 8-ohm speakers, only the power amplifier stage is used. If the input is a microphone, turntable, etc., the preamplifier stage will also need to be used. We'll look at the appropriate wiring schemes in more detail when we discuss the various applications for the amplifier.

Once you've checked your work for accuracy, and you're satisfied that there are no solder bridges, etc. on the board, power can be applied to the circuit. The unit requires at least 9 volts at 200 mA, and will work with power supplies of as high as 12 volts. Obviously, using a 12-volt supply will result in higher levels of audio output. Suitable power supplies are available from a number of sources, including the one mentioned in the Parts List.

Using the amplifier

Normally, those miniature *Walkman*-type personal stereos can only be used with headphones. But if the power amplifier stage of the circuit is used, 8-ohm speakers can be driven from those units.

Figure 4 shows the input wiring scheme that is followed when the unit is used as a personal-stereo amplifier. Note that only the power-amp stage is used; no connections are made to the preamp.

The amplifier is connected to the personal stereo via the stereo's headphone jack. Thus, the input to the amplifier must be connected to a miniature stereo phono plug as shown. Note the two 33-ohm resistors connected across each channel. Personal-stereo outputs are designed to feed headphones, not amplifier/speaker

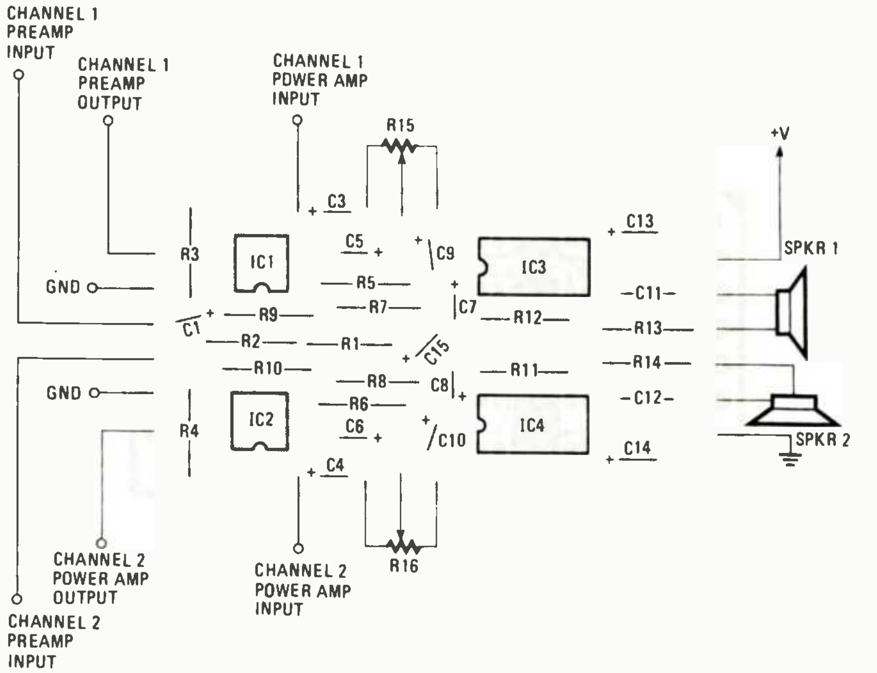


FIG. 3—PARTS-PLACEMENT DIAGRAM. Both the power amp and the preamp circuits are contained on this board.

combinations. Thus, those resistors are included in the input for impedance matching. Alternately, if the stereo has two headphone output sockets, as most do, you can leave one set of phones connected to the unit. Then, the 33-ohm resistors are not necessary.

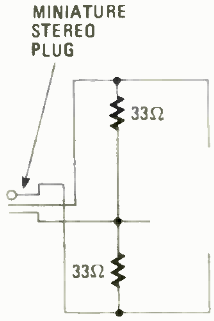


FIG. 4—USE THIS INPUT WIRING SCHEME when using the circuit to amplify the signal from a personal stereo. The 33-ohm resistors are used for impedance matching with the personal stereo's headphone output.

If the input is to be a microphone, turntable, or any other low-level source, the preamplifier stage must be used. In that case, the signal source is input to the preamplifier, and the output of the preamplifier is fed to the power amp. If that is done, input signals ranging from 3.5-mV to 100-mV rms can be accepted.

By using the twin output stages in a "bridge" mode, the output power can be approximately doubled (to 3 watts). If that is done, the circuit can be used as a mini PA amplifier.

To use the circuit for such an application, the speaker is connected across the active output points of each amplifier as shown in Fig. 5. Let's look at that circuit in a little more detail.

In that circuit, the channel-1 preamp is used as an input stage with a gain of 21; it can accept inputs ranging from 3.5 to 100 mV. The channel-2 preamp, however, has been modified (compare the circuit to the one shown in Fig. 2). Now, the gain of that stage has been reduced to unity by changing the feedback resistor, R10, to 47K. That stage now acts as an inverter. That satisfies the requirements of the bridge output; that is, one input is positive-going while the other is negative-going. In other words, the inputs to the output (power amp) stages are 180 degrees out of phase. That provides twice the voltage swing across the 8-ohm load for a given supply, thereby increasing the output power by a factor of four over that of a single stage.

The key factor limiting the amount of power that that circuit can deliver to the load is power dissipation. Because of that, we have limited the power supply to a maximum of 12 volts. That, as previously stated, will result in a maximum power output of about 3-watts rms. To obtain more power you could attach a heatsink bent from a piece of copper 1.5″ on a side. Bend two wings up at a 30° angle, leaving a ¼-inch strip down the center. Glue the center—wings up—to the output IC's with epoxy.

Note that in the dual configuration, both volume controls need to be adjusted equally to control the output. **R-E**

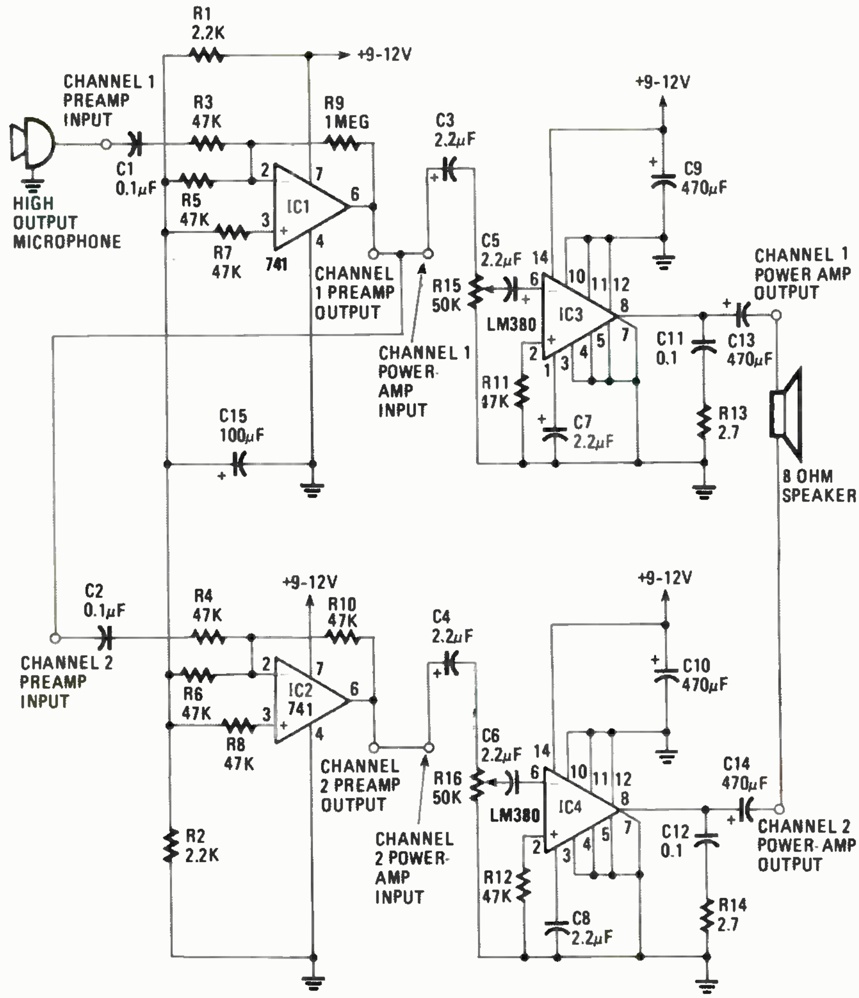


FIG. 5—THE CIRCUIT can be used as a small PA amplifier if it is wired up as shown here. The output of this circuit will be about 3-watts.

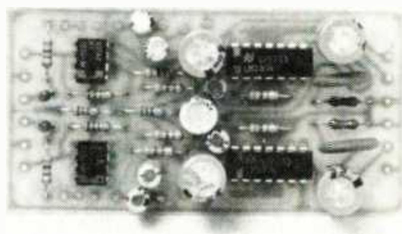


FIG. 6—FOUR IC's comprise this simple, yet versatile amplifier. A single-channel amp with double-power output can be configured.

PARTS LIST

All resistors ¼ watt, 10%, unless otherwise noted
R1, R2—2200 ohms
R3–R8, R11, R12—47,000 ohms
R9, R10—1 Megohm
R13, R14—2.7 ohms
R15, R16—50,000 ohms, potentiometers, audio taper

Capacitors
C1, C2—0.1 μF, 16 volts, tantalum
C3–C8—2.2 μF, 16 volts, electrolytic
C9, C10, C13, C14—470 μF, 16 volts, electrolytic
C11, C12—0.1 μF, ceramic disc
C15—100 μF, 16 volts, electrolytic

Semiconductors
IC1, IC2—741 op-amp
IC3, IC4—LM380 audio amplifier

Miscellaneous: PC board, speaker, hook-up wire, etc.

The following is available from Dick Smith Electronics, Inc., PO Box 8021, Redwood City, CA 94063: Kit of all components, including PC board, but excluding speakers and power supply (K-2667) $14.95 plus $3.00 shipping. A 12V, 500 mA power supply (M-9555) is available for $6.95, plus $3 shipping ($1 if ordered with the amp. California residents must add 6.5% sales tax. Orders outside U.S. must remit U.S. funds and include $5 for shipping.

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AXP87

STEREO TV Decoder

Are you still listening to TV in mono? Double your TV-listening pleasure with this stereo-TV decoder!

STEVE SOKOLOWSKI

STEREO SOUND—IT'S THE MOST EXCITING thing to happen to television since color! Now's the time for *you* to find out how exciting it can be. We explained what it is and how it works a year ago (in the February and March 1985 issues of **Radio-Electonics**). Now it's time to get your hands dirty. Our simple, one-IC circuit will double your viewing pleasure, yet it can be built for about the cost of a single pre-recorded videotape. But before we dive in to discuss circuit operation and construction, let's quickly review the basics of MTS (*M*ulti-channel *T*elevision *S*ound) transmission.

Stereo-TV signals

As with standard FM-broadcast signals, the stereo-TV audio signal has three components. As shown in Fig. 1, they are: the pilot signal, left + right (L + R) audio, and left − right (L − R) audio. In a conventional TV receiver the L + R signal, or the *main channel* is the only one that is detected—it's the monaural signal that you normally hear through your TV's speaker. Note that it is a frequency-modulated (FM) signal with a 75-μs pre-emphasis, and a bandwidth of about 15 kHz.

Just above the main channel is the *pilot* tone, which is used to alert the receiving circuitry that the L − R signal, or the *stereo-difference* subchannel is available for processing. The MTS pilot signal is 15.734 kHz—the standard TV horizontal-scanning frequency, f_H.

As you can see in Fig. 1, the L − R signal or *stereo subchannel* occupies the TV baseband frequency ranging from $2f_H$ to $3f_H$.

MTS allows for additional subchannels that can be used for a number of purposes. One possible audio-baseband configuration is shown in Fig. 1. That configuration incudes two additional subchannels: the SAP, or *S*econd *A*udio *P*rogram, channel (which can be used for bilingual broadcasts and other program-related material) and the *professional channel* (which can be used for communicating with remote news crews, and other non-program-related purposes.) Our stereo adapter cannot decode any of those additional subchannels.

Stereo TV is generated in a manner quite similar to the manner in which broadcast FM is generated. As shown in Fig. 2, separate left and right audio inputs are applied, after low-pass filtering, to the matrix that provides the stereo sum (L + R) and difference (L − R) signals. The sum, or monophonic, signal gets the 75-μs pre-emphasis; it is then clipped, filtered, and mixed with the difference signal. Rather than pre-emphasis, the L − R signal is processed by the *dbx* compressor/noise-reduction system. (See the article mentioned above for information on how that system works.)

Those audio signals are then mixed with the 15.734-kHz pilot signal, which, as we said above, is derived from the the horizontal sync. The resulting signal is filtered and then sent to the audio-modulation circuitry where it is modulated in the usual manner.

To receive stereo TV signals, all we really need is a circuit that will process that composite-audio signal in the converse manner. The basic idea is indicated in Fig. 3. The "TV detector" block separates the sum and difference channels, each of which is filtered (and expanded, if necessary). Then the L + R and L − R signals are applied to a matrix circuit that restores the original left and right channels. At that point they're ready for ampli-

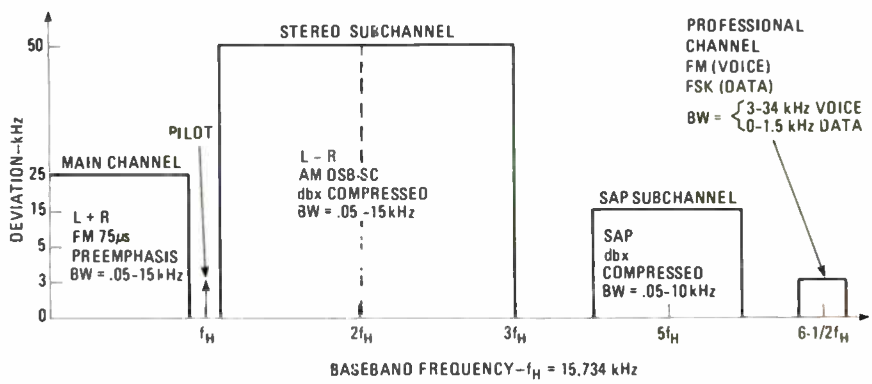


FIG. 1—THE MTS DISTRIBUTION OF SIGNALS provides for a monaural main channel, sub-channels for the stereo sub-carrier and a secondary audio program (SAP), and a professional channel for voice or computer (FSK) data.

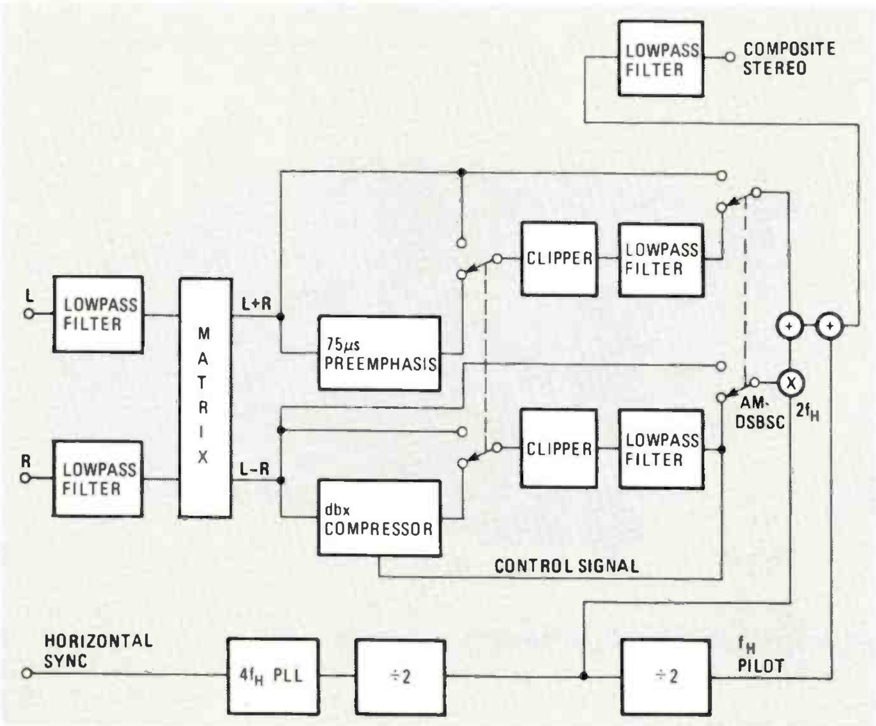


FIG. 2—**MTS STEREO IS GENERATED** in a manner similar to that of standard broadcast FM. MTS differs from broadcast FM in that it uses *dbx* noise-reduction, and the standard TV horizontal-scan frequency to generate the pilot tone.

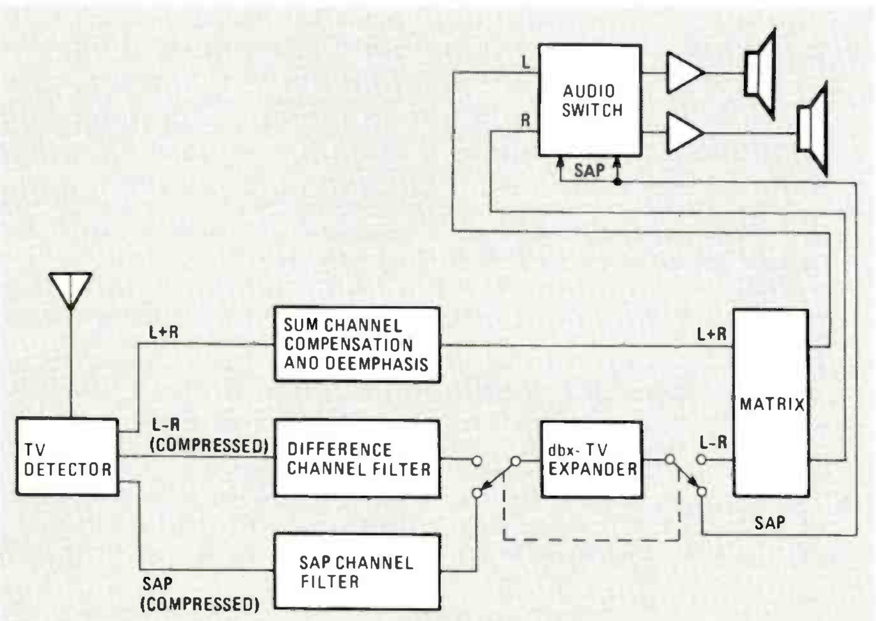


FIG. 3—**THE ORIGINAL LEFT- AND RIGHT-CHANNEL AUDIO SIGNALS** are recovered in the matrix decoder after filtering and de-emphasis of both L + R and L − R, and after expansion of the L − R signal by the *dbx* unit.

fication. (Note that the block diagram in Fig. 3 includes a SAP decoder, which our stereo adapter does not offer.)

If you're wondering how the original channels can be extracted from the sum and difference signals, examining the following equations should clear things up:

$$(L + R) + (L - R) = 2L$$

$$(L + R) - (L - R) = 2R$$

In other words, we can restore the left channel by adding the sum and difference signals, and we can restore the right channel by subtracting the difference signal from the sum signal. At that point all we have to do, in order to provide usable stereo-TV signals, is provide power amplification. So how can we extract the left- and right-channel signals?

Circuit description

The schematic of the stereo-TV decoder is shown in Fig. 4. Assume for now that it is connected to a proper source of composite audio. We'll show you how to do that in a minute.

The composite input signal is preamplified by transistor Q1 and is then coupled to the high-pass filter composed of C3, C4, R6, and R7. The filtered audio is then passed to IC1, an MC1310P "Coil-less Stereo Demodulator." That IC is normally used to demodulate broadcast-band FM signals, but by changing the frequency of its on-board VCO (*V*oltage *C*ontrolled *O*scillator) slightly (from 19 kHz to 15.734 kHz), we can use that IC to detect stereo-TV signals.

A block diagram of the MC1310P is shown in Fig. 5. Notice that the components connected to pin 14 control the VCO's frequency, hence the pilot-detect and carrier frequencies. For use in an FM receiver, the VCO would run at four times the 19-kHz pilot frequency (76 kHz), but for our application, it will run at four times the 15.734-kHz pilot frequency of stereo TV, or 62.936 kHz.

The MC1310P divides that master VCO signal by two in order to supply the 31.468 kHz carrier that is used to detect the L − R audio signal. The L − R signal undergoes normal FM detection, and at that point we've got two audio signals: L + R and L − R. The *decoder* block in the IC performs the addition and subtraction to produce the separate left and right signals.

Referring back to the schematic in Fig. 4, R10 and C10 form a de-emphasis network that compensates for the 75-μs pre-emphasis that the left channel underwent; R12 and C11 perform the same function for the right channel. Now we've completely restored the original audio signal—almost.

You'll recall, in Fig. 3, the *dbx* expander circuit. We have provided no *dbx* expansion because *dbx* IC's haven't been released for general distribution. (They're available only to licensed OEM's.) So to provide some noise reduction (which will be necessary if you live in a less-than-ideal reception area), what we can do is connect our adapter to a non-*dbx* noise-reduction system. Alternatively, we can connect our adapter to a stereo system with a built-in noise reduction system. (*Another possibility would be to connect the stereo-TV decoder to the experimental compander discussed in the November, 1985 issue of* **Radio-Electronics**—*Editor.*)

None of those solutions is perfect, so the stereo TV you'll receive is less than ideal. However, we'll get no stereo TV at all if we don't start building an adapter—so let's do it now!

Construction

Since we're not dealing with very high frequencies, the adapter can be built in just about any convenient manner. A PC board will simplify construction, though, so we've included a foil pattern in "PC

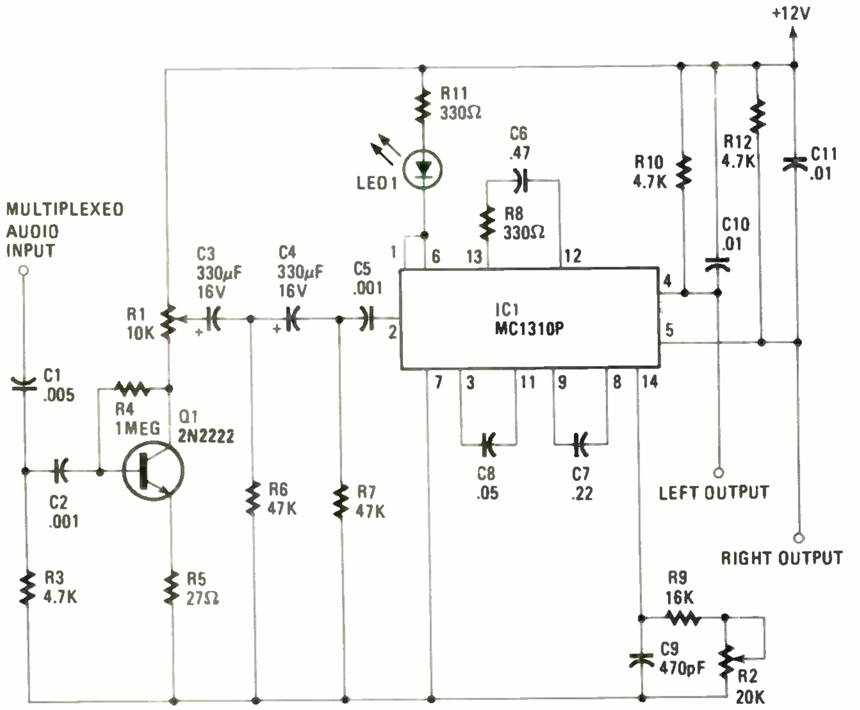


FIG. 4—THE CIRCUIT OF OUR MTS ADAPTER is quite simple, as shown here. The transistor provides a little pre-amplification for the IC (an MC1310P), which decodes the left and right audio channels.

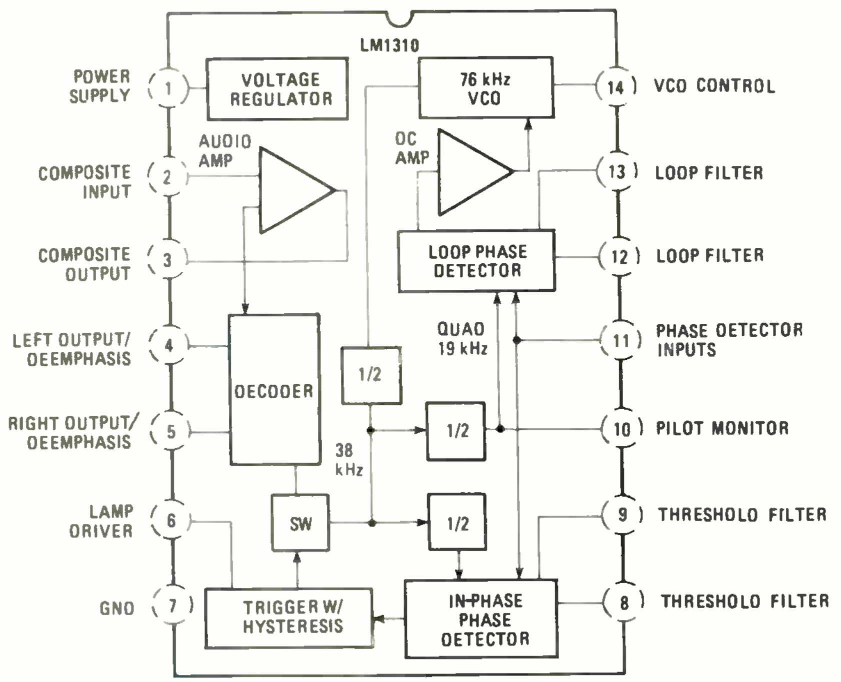


FIG. 5—THE MC1310P WAS DESIGNED FOR BROADCAST-FM decoding, but the stereo-TV pilot tone and carrier can be generated by altering the IC's VCO frequency from its nominal 76-khz value.

Service." You can also buy a PC board and a kit of parts; see the Parts List for more information.

Use the parts-placement diagram in Fig. 6 and the photo in Fig. 7 as a guide for mounting all components. Use a socket for IC1. Be sure to orient Q1 correctly, and don't apply too much heat to the transistor.

In Fig. 7 you'll notice a small board to the right of the main PC board. That's a 7812 regulator circuit that supplies 12-volts DC for the circuit. The schematic of that circuit is shown in Fig. 8. The foil pattern for the power-supply board is also shown in "PC Service," and the parts-placement diagram is shown in Fig. 9. For our prototype, we used a small wall-mount transformer to supply AC to the power supply.

PARTS LIST—MAIN BOARD

All resistors ¼-watt, 5% unless otherwise noted.

R1—10,000 ohms, audio taper, PC-mount, trimmer potentiometer
R2—20,000 ohms, linear taper, PC-mount, trimmer potentiometer
R3, R10, R12—4,700 ohms
R4—1 megohm
R5—27 ohms
R6, R7—47,000 ohms
R8, R11—330 ohms
R9—16,000 ohms

Capacitors

C1—0.005 µF, ceramic disc
C2, C5—0.001 µF, ceramic disc
C3, C4—330 µF, 16 volts, electrolytic
C6—0.47 µF, ceramic disc
C7—0.22 µF, ceramic disc
C8—0.05 µF, ceramic disc
C9—470 pF, ceramic disc
C10, C11—0.01 µF, ceramic disc

Semiconductors

IC1—MC1310P or LM1310 or XR1310 "Inductor-less" FM stereo demodulator
Q1—2N2222
LED1—Standard red LED

Note: A kit containing the main PC board and all parts that mount on it is available for $30.00 plus $1.50 for shipping and handling. Order from Del-Phone Industries, Inc., P. O. Box 150, Elmont, NY 11003. New York residents must add applicable sales tax.

When you've got the PC boards assembled, check them over carefully for solder bridges between adjacent pads and traces on the PC board. And make sure that all polarized components—IC1, Q1, LED1, the electrolytic capacitors—are installed correctly. When everything looks OK, it's time to align and install the adapter.

Alignment

You'll need an audio oscillator and a frequency counter to align the adapter. Connect the frequency counter to the oscillator and adjust the oscillator for a frequency of exactly 15.734 kHz at about ½-volt p-p. Then connect the output of the oscillator to the input of the adapter, and apply power. Adjust trimmer potentiometer R1 to its center position, then adjust trimmer potentiometer R2 until LED1 illuminates. If you have trouble getting the LED to light up, adjust R1 to allow more signal to get through to IC1.

If you don't have an audio oscillator and a frequency counter, you can align the adapter by connecting your adapter to a source of composite TV audio, as described below, and then tuning in a local station that you know is broadcasting in stereo. With the adapter connected to your stereo system, and R1 set in the center of its range, slowly adjust R2. Watch for the LED to light up, and then adjust R1 and R2 for best received audio.

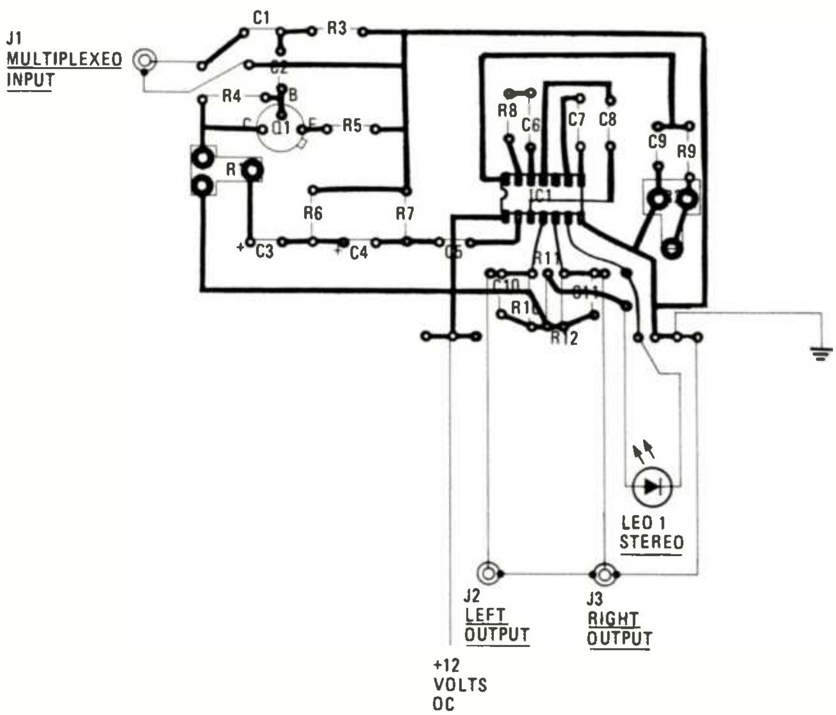


FIG. 6—THE STEREO-TV DECODER'S COMPONENTS are located on the PC board as shown here.

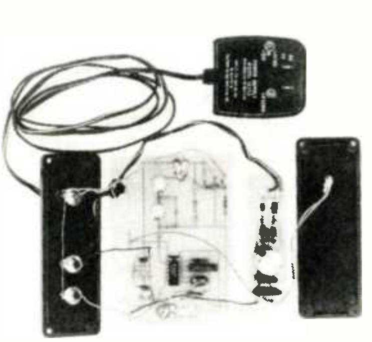


FIG. 7—YOUR STEREO-TV DECODER'S PC BOARD should look like this after all components are mounted.

That completes alignment! What we did was simulate the 15.734-kHz pilot signal with the audio oscillator. When the adapter is properly connected to a VCR or TV that is receiving a stereo signal, the LED will light up to indicate that a stereo signal is being received—just as the STEREO indicator on a standard FM receiver does.

Adapter installation

Connecting the adapter to a source of composite audio is potentially the most difficult part of this project. We'll describe five different possibilities.

Don't get any ideas about using the earplug output of your TV, VCR, or radio.

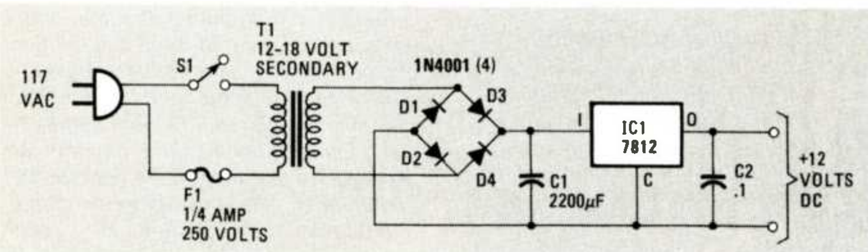


FIG. 8—THIS POWER SUPPLY provides plenty of power for the stereo-TV decoder.

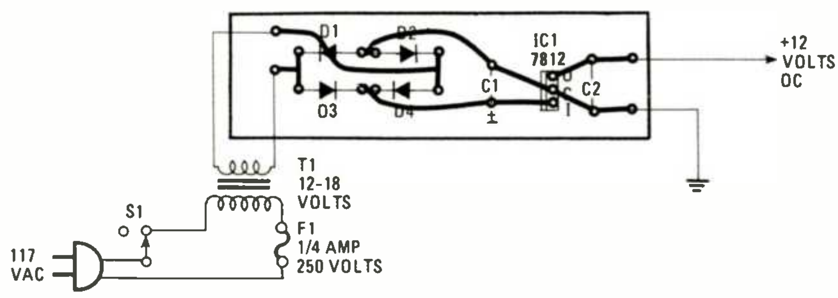


FIG. 9—PARTS PLACEMENT diagram for the power supply board.

PARTS LIST—POWER-SUPPLY
IC1—7812 12-volt, 1-amp regulator
D1–D4—1N4001 power rectifier
C1—2200 µF, 25 volts, electrolytic
C2—0.1 µF, monolithic
Other components
F1—¼-amp, 250 volts
J1, J2, J3—RCA phono jack
S1—SPST, miniature toggle
T1—12–18-volt wall-mount transformer

First, there will be too much distortion—you have to pick up a low-level signal. Second, the output will not contain the proper composite signal.

VCR connection—You *may* simply be able to connect the adapter to the audio output on the back of your VCR. Unfortunately, the adapter will not operate correctly with most VCR's because many manufacturers filter out the necessary signals and leave only the main channel. But it's certainly worth a try.

External-TV connection—If you purchased a TV recently, you may be in luck. If your TV has an stereo output jack, just connect the input of your adapter to that jack.

Internal-TV connection—**Warning**—Don't attempt this sort of connection unless you are sure you know what you are doing and you have complete documentation for your TV. The high voltages in your TV are hazardous to your health, and the health of your adapter! Remove the back of your TV and solder a shielded cable to the output of your set's audio detector. Connect the other end to the adapter.

Internal-VCR connection—**Warning**—Don't attempt this sort of connection unless you are sure you know what you are doing and you have complete documentation for your VCR. One mistake could be very expensive! As with the previous method, locate the audio detector IC. Then solder one end of a shielded cable to that point. Connect the other end to the audio input of the adapter.

Radio connection—If you have a table or portable radio that can receive TV audio, *carefully* connect one end of a shielded cable to the audio detector's output. Connect the other end to the adapter's input.

Whichever method of installation you choose, connect the outputs of the adapter to your stereo amplifier's (or receiver's) auxilliary inputs and fine-tune the alignment.

Conclusions

Stereo TV is still new, so even though many programs are now recorded in stereo (such as *Johnny Carson* and *Miami Vice*), not all stations are equipped to broadcast stereo audio. For a partial listing, check the back issues of **Radio-Electronics** mentioned above, or call your local TV stations. **R-E**

Mini Music Synthesizer

Turn your voice into a versatile musical "instrument" with this fun-to-build mini music synthesizer.

THIS MINI-MUSIC SYNTHESIZER IS NOT TOO complex, but it is a load of fun to build and use. The ingenious little unit samples and holds the frequency of a signal from a microphone or other sound source and outputs that signal as a single note. The input "signal" can be a whistle, hum, or some other sound. The duration and amplitude of the note can be controlled. The frequency of the note can be halved or doubled with a flick of a switch. A vibrato effect can also be applied via a variable tremolo control. To add to all of that, two channels are available to give chorus or stereo effects. Each of those channels has a separate volume control.

The signal source is derived from a low- to medium-impedance microphone. That microphone can be almost any dynamic or electret type. The types used with low-cost cassette recorders will work well.

The synthesizer's output is connected to an external amplifier of some type. A home-stereo system would be suitable: feed the signal to the auxiliary or tuner input. A PA amplifier could also be used.

How it works

The schematic of the synthesizer is shown in Fig. 1. As you can see there, its input section is basically a microphone amplifier and signal shaper with three stages. Twin *V*oltage *C*ontrolled *O*scillators (VCO's) each with a *V*oltage *C*ontrolled *A*mplifier (VCA) output stage make up the main section. The remaining circuitry is a simple, adjustable low-frequency oscillator that's used as a tremolo-effects generator.

The first stage of the input section is made up of IC1-a and its associated circuitry. That stage has a gain of about 100 at 1 kHz. The op-amp circuit used in that stage is very basic. Note, however the presence of the capacitor in the feedback loop. That capacitor causes a roll-off in gain as the input frequency increases. The output of the amplifier is AC coupled to the next stage by C7.

The second stage consists of IC1-b and its associated circuitry. That stage has a gain of about 20. Like the previous stage, the high frequency response is limited by a capacitor in the feedback loop. That response tailoring has been done to reduce the normally rich harmonic content of the human voice; the only signal we want to process is the fundamental note. The harmonics are low in amplitude and can be partially rejected by the simple approach used in that circuit.

The last stage of the input section is the most significant and needs some explanation. The op-amp there, IC1-c, is configured as a Schmitt trigger with offset. The hysteresis components are R22 and R21. Normally a Schmitt trigger is bistable, and in the quiescent state the output would be either positive or negative depending on the last signal transition. The difference in this case is that the offset voltage at the inverting input is greater than the hysteresis voltage at the noninverting input; resistors R20 and R39 establish that offset. The purpose of the offset is to assure that the output at pin 8 of IC1 is always low (negative) when no signal is present. The output will only switch when the input exceeds the sum of the hysteresis and offset voltages. The circuit acts as a gating system to the following phase-locked loop circuits.

The Schmitt trigger is the second stage of the processing that rejects the harmonics and noise in the input signal from the microphone. The input level, set by R41, is adjusted by turning that control until reliable response is achieved from a normal-level input (such as a singing voice). It is not adjusted farther than that minimum amount. In that way, the Schmitt trigger will tend to switch only on the peaks of the fundamental. The levels of the harmonics and noise content of the signal are below the threshold switching points and will be rejected. The purer the voice or note, the more reliable the circuit action. A "gravelly" or "rough" voice thus will tend to prove unreliable as a signal source. The best results will be from a whistle, because that produces a note that is relatively free from harmonics of any amplitude.

From the output of IC1-c, the signal is split and fed to both the right and left channels. Since the circuitry in the two channels is identical, we will look at only one of those: channel 1.

Adapted from a project that originally appeared in Dick Smith's *Funways into Electronics*, volume three.

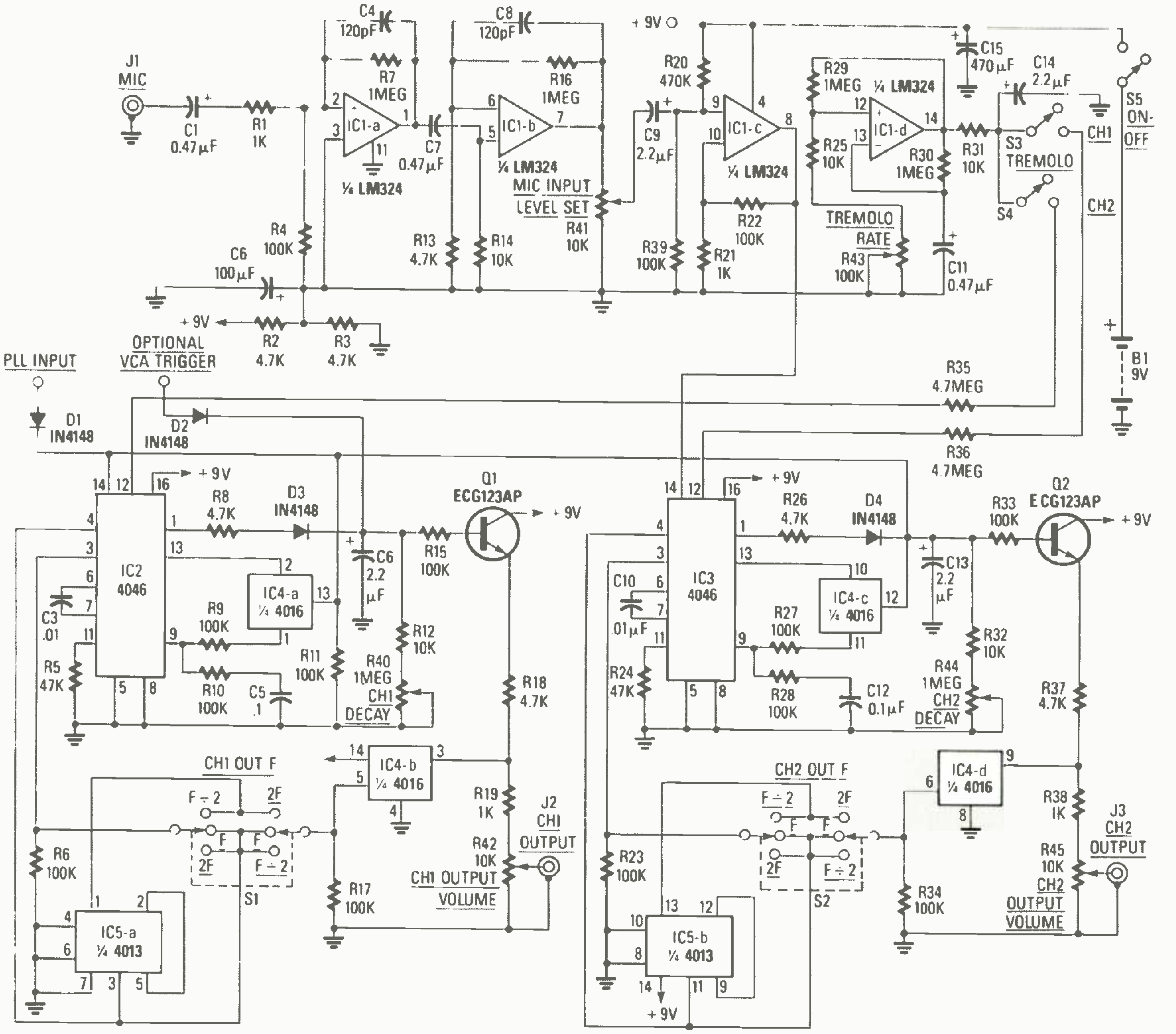


FIG. 1—SCHEMATIC DIAGRAM of the mini synthesizer. The potentiometers can be either panel-mounted or PC-mounted.

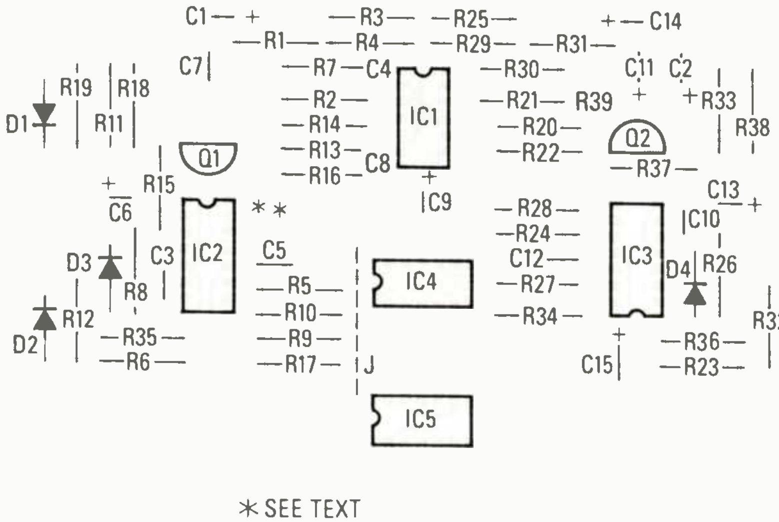


FIG. 2—THE LOCATIONS OF ALL PC-board mounted components are shown here. To disconnect the microphone input stage, cut the trace between the pads marked with an asterisk.

From the Schmitt trigger, the signal is passed to IC2, a 4046 CMOS *Phase Locked Loop* (PLL). That IC consists of two separate circuits. One is a VCO that runs from subaudio to over 1 MHz. The other is a dual-output phase comparator. By adding just a few external components, a complete PLL can be formed. (For more information on the 4046, see the manufacturer's data sheet.)

Without an input signal, the output of the Schmitt trigger will be low, and therefore pin 13 of IC4-a, a 4016 analog switch, will also be low. That means that the analog switch will be off, and pin 13 (PLL COMPARATOR-OUTPUT 2) of the 4046 will be disconnected from pin 9, the input to the VCO. The voltage present on the lowpass filter capacitor (C5), together with the RC timing components (C3 and R5), will determine the frequency of the

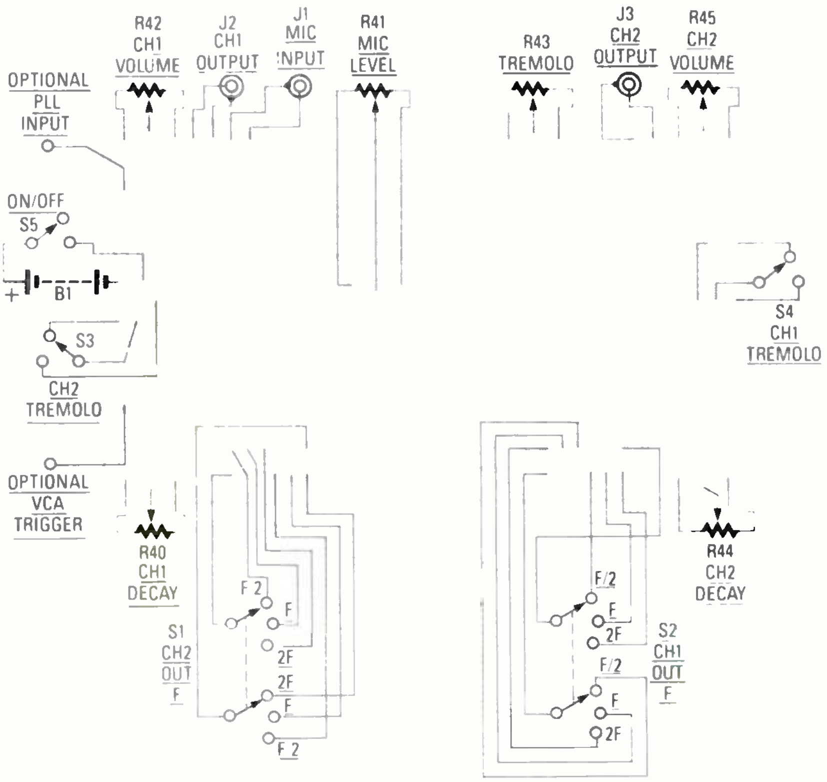


FIG. 3—**THE OFF-BOARD COMPONENTS** should be connected to the PC board via wires.

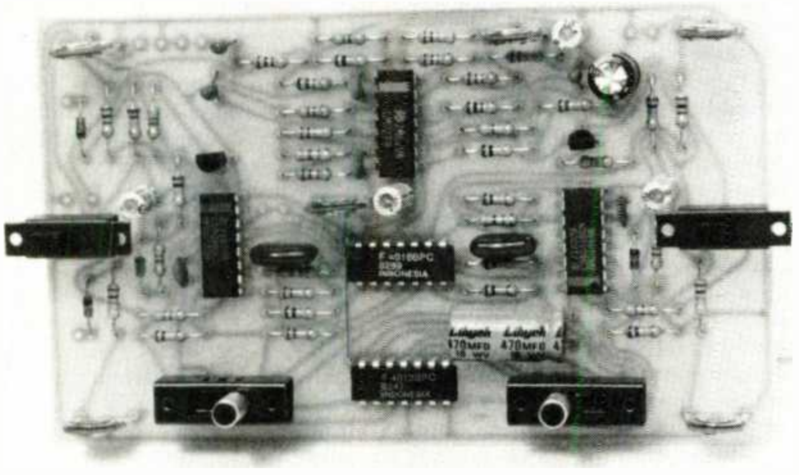


FIG. 4—**THE FINISHED PC-BOARD** is shown here. Note the use of PC-mounted trimmers in this version.

PARTS LIST

Resistors

All resistors are ¼-watt, 5%, unless otherwise noted.

R1, R19, R21, R36—1000 ohms
R2, R3, R8, R18, R26, R37—4700 ohms
R4, R6, R9–R11, R15, R17, R22, R23, R27, R28, R33, R34, R39—100,000 ohms
R5, R13, R24—47,000 ohms
R7, R16, R29, R30—1 megohm
R12, R14, R25, R31, R32—10,000 ohms
R35, R36—4.7 megohms
R40, R44—1 megohm, potentiometer, linear taper
R41, R42, R45—10,000 ohms, potentiometer, audio taper
R43—100,000 ohms, potentiometer, linear taper

Capacitors

C1, C7, C11—0.47 µF, 10 volts tantalum
C2—100 µF, 16 volts, electrolytic
C3, C10—0.01 µF, ceramic disc
C4, C8—120 pF, ceramic disc
C5, C12—0.1 µF, polyester
C6, C9, C13, C14—2.2 µF, 16 volts, electrolytic
C15—470 µF, 16 volts, electrolytic

Semiconductors

IC1—LM324 quad op-amp
IC2, IC3—4046 CMOS PLL
IC4—4016 quad analog switch
IC5—4013 dual D flip-flop
Q1, Q2—ECG123AP NPN transistor
D1–D4—1N4148 silicon diodes

Other Components

S1, S2—DP3T miniature slide switch
S3–S5—DPDT miniature slide switch
J1—miniature phone jack
J2, J3—phono jack
B1—9-volt battery

Miscellaneous: PC board, case, knobs, battery snap, wire, etc.

A kit of parts (Catalog Number K-2669) is available from Dick Smith Electronics, PO Box 8021, Redwood City, CA 94063. The kit includes the PC board, but not the case, the battery or the jacks. The price is $19.95.

VCO. The voltage across C5 will not dissipate for a long period of time, because of the very high input impedance at pin 9 of the 4046, and the low-leakage characteristic of that 0.1-µF polyester capacitor. That, in turn, means that the output frequency of the VCO at pin 4 will remain stable for a long period of time.

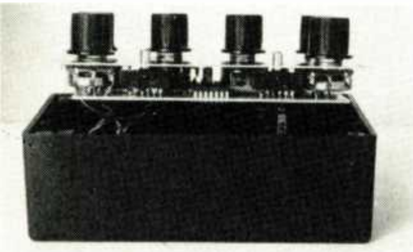
Now let us look at what happens when an input signal is present. Pins 13 of the analog switch and 12 of the PLL will go high. The analog switch is then on, and the phase-comparator output of the PLL (IC2, pin 13) will be connected to the VCO (IC2, pin 9) via the lowpass filter (R9, R10, and C5). Provided that the input signal continues at a fixed frequency for a short period of time, the PLL will lock in and follow any frequency variations. For the most part, in that locked state, the PHASE PULSE output (pin 1) will be high (there will, however, be some narrow negative-going pulses).

With pin 1 of the 4046 high, D3 will be forward-biased via R8, so C6 will charge. The voltage across the capacitor is applied to the base of Q1, which acts as a voltage follower/buffer. That transistor is half of the VCA output stage, the other section being another 4016 analog switch (IC4-b). The control gate (pin 5) of IC4-b is connected directly to the output of the VCO (pin 4 of IC2), or indirectly via the 4013 (a dual D flip-flop), depending on the setting of S1. The squarewave output from the VCO opens and closes the analog switch. It can be seen that that action directly gates the voltage available to the output terminal via the two current limiting resistors and the potentiometer.

When the input signal disappears, pin 1 of the 4046 returns low. As described previously, the VCO remains running at a frequency determined by the voltage on capacitor C5. The voltage across C6 then begins to discharge via the transistor follower and the two resistors, R12 and R40. Those two resistors control the "decay" rate. If R40 is set to its maximum value (1 megohm) the discharge time will be long (decay will occur slowly). As the discharge is taking place, the continuous output from the VCO switches the analog gate IC1-b on and off to "sink" the decaying voltage on the emitter of Q1 via the load resistor (R18) at the VCO rate.

The frequency of the note reaching the output stage can be changed from that of the original. By using a flip-flop as a divide-by-two element, the output can be halved or doubled depending on where it is coupled into the circuit. With the octave-select switch (S1) in the center position (F), the output frequency will be identical to to input. When the F/2 position is selected, the 4013 (configured as a clocked flip-flop) divides the output from the VCO (IC2, pin 4) by two (lower octave). In the 2F position, the flip-flop is connected between the output of the VCO and the comparator of the PLL. That results in a frequency that is twice that of the input (upper octave) at pin 4 of the VCO.

So far we've only used three sections of the LM324 quad op-amp. The fourth section (IC1-d) is used as a tremolo generator. The op-amp is configured as an astable multivibrator to give a squarewave output. Potentiometer R43 is included to adjust the frequency (tremolo rate). The squarewave is then smoothed somewhat to give a more natural tremolo effect to the output note. That waveform is then applied to the VCO (at pin 12, IC2) via a selector switch and a 4.7 megohm resistor.



ONCE COMPLETED, the circuit should be installed in a case.

Optional inputs

The VCA of either channel can be triggered from an external source. A positive pulse input via D2 to the VCA will charge C6. If that input is held high, the output from the VCA will also remain high. If the input is a pulse from a sequencer or even a simple switch, the output from the VCA can be triggered without the need for an audio signal at the microphone input. That could be used with rhythm generators, etc., to create different effects. The frequency of the VCO can still be changed by using the microphone input. If you require that the input signal from the microphone-amplifier stage not trigger the VCA, create an open circuit by removing D3 from the board. (The foil pattern for the project is provided in our "PC Service" department; the parts-placement diagrams are shown in Figs. 2 and 3.)

By disconnecting the input stage from the VCO, the PLL can be used separately by providing an external input signal. Isolation is performed by cutting the PC board trace between the pads marked with an asterisk in Fig. 2. The input is applied via D1. That input should be a squarewave. The peak-to-peak voltage of the input should not greater than the circuit's supply voltage, and should not be less than 75% of the supply voltage. If the input stage is disconnected from the PLL in the manner described, the circuit could be used to modify the output of an electronically amplified instrument or a sound generator (provided that the input signal meets the requirements of the 4046). For example, the output from a simple monophonic organ can be used to create more interesting tones and sound effects. The decay control could be used to vary the note shape, and the octave switch can change the note frequency.

To reconnect the PLL to the microphone input stage, the link destroyed when the PC trace was cut must be restored. That is done by installing a jumper between the pads marked with an asterisk in Fig. 2; for convenience, that jumper could be replaced by a switch.

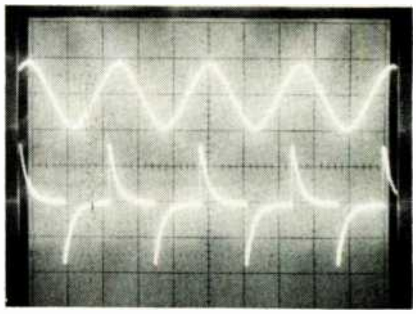
Assembly

Assembly is very straightforward if you follow Figs. 2 and 3. Start by mounting all of the low-profile components on the board. Those include the resistors, diodes, and the jumper. Next, install the capacitors. Be sure to observe the polarity of the electrolytics. After that, install the IC's and transistors, taking care to observe the proper orientation. Finally hook up the switches, potentiometers, and other off-board components. Note that the board has been designed to accept PC-mount potentiometers, but you can use panel-mount potentiometers and connect them to the board with wire.

To test the system you will need to use an audio amplifier of some type. Feed the output of the synthesizer to the amp, plug in the microphone and battery, and turn the unit on. Whistle a few times close to, but not directly into the microphone. Turn up the MICROPHONE INPUT LEVEL SET control until some response is heard from the outputs. Set the VOLUME controls of both channels to an appropriate level. Vary the pitch (frequency) of your whistle; the output should vary in kind.

Next, try varying the DECAY controls. With the controls set to maximum, you will hear the outputs change in frequency as the note of your whistle changes. Notes that are wide apart in frequency will take a little longer to lock. Now try changing the setting of the OCTAVE SELECT switches. Also try out the TREMOLO RATE control; be sure that the tremolo section is switched into the circuit when you do that.

If all is working, the completed board (see Fig. 4) can be mounted in a case to complete assembly. If you detect any problems, go over your work carefully to find the cause of the problem.



THE UPPER TRACE is a 3-kHz input signal from a signal generator. The bottom one is the output that results.
(Photo courtesy of Tektronix)

Operation

Connect the microphone and switch the unit on. Now slowly whistle a tune a short distance from the mouthpiece. Do not blow directly into the microphone. Best results are obtained with the microphone at the side of your mouth so that any air currents do not hit it directly.

Turn the input-level control up until you get a reliable response from the unit every time a note is whistled at the same volume. Turn the output-volume controls to a suitable level to avoid feedback. The whistled note should be a short, clean burst. Try changing the DECAY controls so that the generated sound varies from a short staccato to a long, slowly-decreasing tone.

Note that the synthesizer is sensitive to all sound. Thus, when the microphone picks up the output sound of the amplifier, feedback occurs and the system locks up in an uncontrolled state. To avoid that, you must keep the microphone away from the speaker system.

When you find a suitable input level, try the other functions. By changing the OCTAVE SELECT switches, the output frequency can be set to be the same as the input, or one half of the input, or twice the input. By adding tremolo to one or both channels, interesting tonal effects can be achieved.

Try singing or humming into the microphone as the sound source. The system will respond best to pure, clean notes. Rough voices will not be reliable.

By striking different shaped objects next to the microphone, the system will tend to pick up the fundamental resonance of the object and produce an equivalent note.

Musical instruments can also be used as the sound source. A simple recorder, for instance, can produce many and varied sounds. Other instruments, such as a guitar, can produce different notes and sounds., The combinations are endless.

To give greater versatility to the unit, channel one can be controlled from external sources as described above. With a little practice, this mini synthesizer can make you a "one-man band." **R-E**

BUILD THIS

$99 Satellite-TV Receivers

RICHARD MADDOX

OK, TVRO fans, here's your chance to build a high-performance satellite receiver—for peanuts!

THE IDEA OF RECEIVING TV SIGNALS FROM satellites became popular almost instantaneously when the first home TVRO was built in 1979. However, due to the tremendous costs involved, the *practice* of receiving TV signals from satellites was nowhere near as popular. Only recently have prices dropped to the point where satellite-TV can be enjoyed by a large number of people.

Receiver kits helped make satellite TV affordable to electronics hobbyists (to whom TVRO was esecially appealing.) But the kits that were available were difficult to build, and they required a lab's worth of expensive test gear to align. But now—thanks to advances in electronics and state-of-the-art circuit design—we can show you how to build a satellite receiver for less than one hundred dollars! It's very easy to build, and requires only your eyes, a TV set, and a voltmeter to align. And that's not all: The receiver performs as well as—if not better than—commercial units costing several times as much.

If you already own a satellite-TV system, this is an ideal opportunity for you to add a second receiver to your system at a very low cost. All that is required is an isolated two-way power divider, a downconverter, and the associated cabling. If you have an older satellite system, and your picture, sound, or both aren't up-to-snuff, then this receiver may be just what you need to improve reception. It accepts a standard 70-MHz input, and features continuous transponder-tuning, tunable audio subcarrier with switchable bandwidth, a polarization control circuit, defeatable AFC, and an integral crystal-controlled RF modulator for output on TV Channel 3 or 4.

Of course, the receiver can't pick up satellite-TV signals all by itself—several other components are necessary. We'll briefly describe what's needed for a complete system. But if you're very unfamiliar with satellite TV, we suggest you check the special sections that appeared on the subject in the June 1984, October 1984, June 1985 and July 1985 issues of **Radio-Electronics**.

Main system components

There are several components, in addition to the receiver, that are needed to complete a TVRO system: the dish, the feedhorn, the LNA (low-noise amplifier), the downconverter, and the cable. We'll examine each of those in turn.

The dish is parabolic in shape, and it is built from metal. The strength of the signal received by the antenna probe in the feedhorn is proportional to the diameter of the dish. Luckily, satellite power levels have increased the past few years to the point that a small dish (four to six feet in diameter) provides adequate reception throughout much of the midwest and south. Throughout the rest of the country, an eight- to ten-foot dish will probably be necessary for good reception, although newer satellites may allow the use of a four- to six-foot dish. Whatever sized dish you use, though, it must be aimed precisely at the desired satellite. Signals from the satellite then hit the dish and are reflected to a point, the focal point of the dish, where the *feedhorn* is located.

The feedhorn has several purposes. It collects the microwaves that have been reflected by the dish, directs them to the LNA, and selects the desired polarity.

To understand why polarity is important, you must understand that TV satellites can broadcast on 24 different channels, numbered 1 through 24. The trick is that the odd-numbered channels are broadcast in a different spatial orientation than the even-numbered channels. That is done because the frequencies of the odd and even signals actually overlap one another. But because they're polarized differently, we can receive one set without interference from the opposite set. We'll discuss more about how that works in the "theory-of-operation" section below.

The *LNA* (low-noise amplifier) is similar to the antenna pre-amp found on fringe-area TV antennas. Its purpose is to boost the satellite signals to a level that can drive the downconverter. The LNA is mounted behind the feedhorn.

The two most important specifications of an LNA are the noise temperature and the gain. Noise temperature is rated in degrees Kelvin; the lower the number, the less noise the amplifier adds to the signal as it is amplified. Gain is measured in dB, and typically ranges between 30 and 55 dB. An average LNA today might have 100°K noise temperature and 50 dB gain, although some high-performance models are rated at 85°K.

Roughly speaking, the noise temperature of the LNA can be correlated to the size of the dish. For example, a ten-foot dish and a 100-degree LNA will give results similar to an eight-foot dish and an 80-degree LNA, or to a six-foot dish and a 60-degree LNA.

The *downconverter* is what actually tunes in the desired channel. It is mounted directly to the LNA or behind the dish on the mount. Downconverters usually have three electrical connections: the input, which comes from the LNA, the 70-MHz output, which goes to the receiver, and an additional voltage that is used to tune in the desired transponder channel. That voltage is set by the user at the receiver. Most common downconverters use a tuning voltage that ranges from two to sixteen volts. Receivers usually supply that tuning voltage to the LNA through the same cable and connector that the 70-MHz signal travels through.

Some downconverters are designed to be mounted directly to an LNA, and must be used with a 30- to 35-dB gain LNA. If a 50-dB LNA is used, it is recommended that the downconverter be mounted behind the dish and connected to the LNA via RG213 cable, unless the dish is smaller than about seven feet, or unless the downconverter is specifically designed to be used with a high-gain LNA.

There are two types of coaxial cable used in typical satellite systems: RG213 and RG59. The standard 75-ohm cable used to hook up TV antennas is RG59, and RG213 is special 50-ohm cable designed for high-frequency use. The LNA is connected to the downconverter with RG213 cable, and two RG59 cables connect the receiver and the downconverter. An additional RG59 cable connects the receiver to the TV set. Finally, the feedhorn is connected to the receiver via a two-conductor shielded cable. One conductor carries the supply voltage from the receiver, and the other provides the polarizing pulses that we'll discuss in a moment. But let's begin at the beginning. Refer to the block diagram in Fig. 1 and the complete schematic diagram in Fig. 2 while following this discussion.

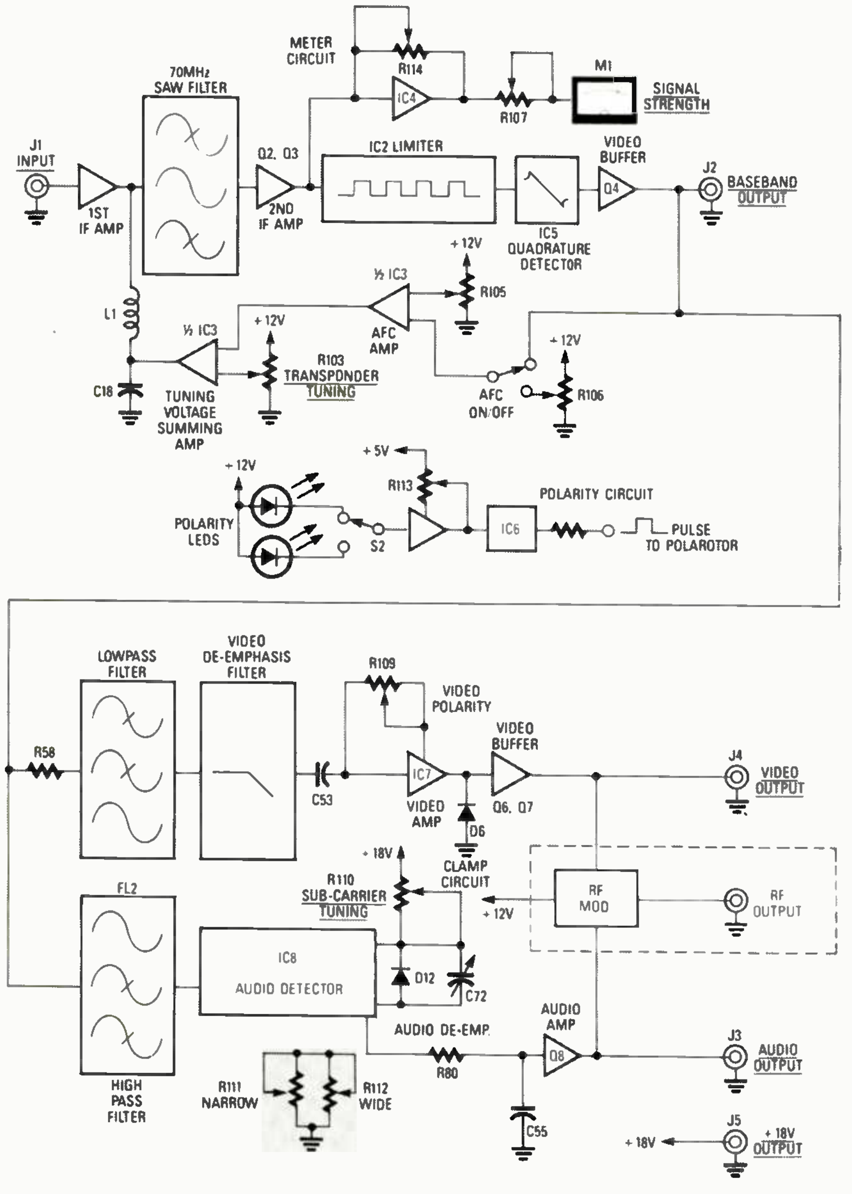


FIG. 1—SATELLITE RECEIVER BLOCK DIAGRAM. When analyzed in segments, the receiver isn't really as complicated as it looks.

Theory of operation

The receiver accepts a 70-MHz signal from the downconverter at jack J1; that jack also supplies the variable tuning voltage to the downconverter. The input signal is isolated from the tuning voltage by inductor L1 and capacitor C18. Front panel potentiometer R103 (TRANSPONDER TUNING) is used to tune in the desired transponder. Trimmer potentiometers R102 and R104 set the maximum and minimum voltages, respectively, presented to the downconverter.

An AFC (Automatic Frequency Control) voltage is derived from the received signal and summed with the tuning voltage by IC3. AFC can be defeated by front-panel switch S1 if terrestrial interference is encountered (or if a synthesized downconverter is used). When AFC is defeated, R106 supplies a compensation voltage for proper tuning.

The 70-MHz input signal is capacitively coupled to IC1, which provides a gain of about 25 dB. Filter FL1 is a SAW (Surface Acoustic Wave) filter with a bandwidth of 27 MHz. Its purpose is to strip off noise and interference occurring on either side of the selected channel.

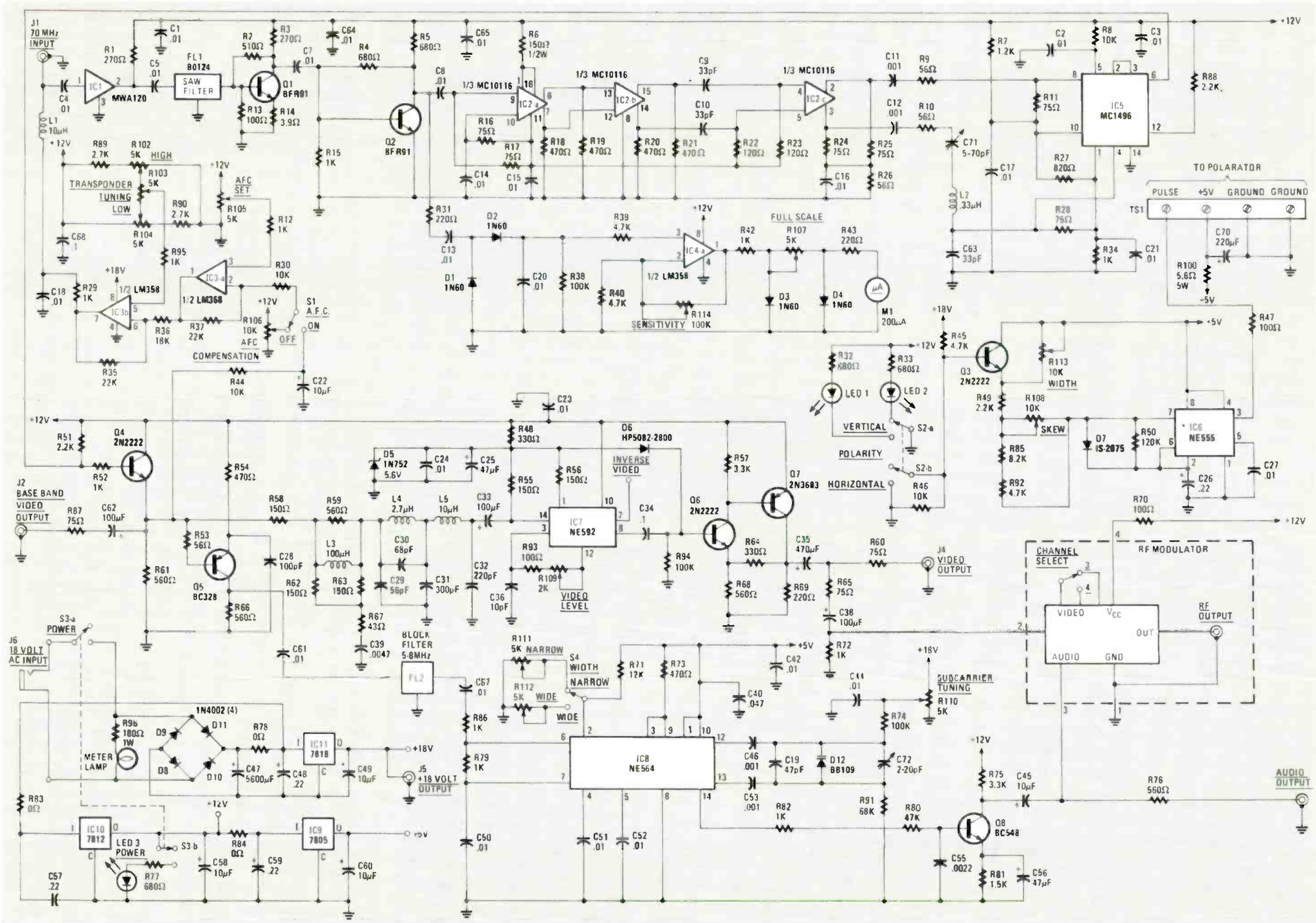


FIG. 2—THE COMPLETE SCHEMATIC of the receiver shows the tuning circuit, the IF section, the video and audio circuits, polarization-control curcuit, RF modulator, and power supply. A complete kit is available, and hard-to-find components, including the PC board, are available separately.

All resistors 1/4-watt, 5% unless otherwise specified.
R1, R3—270 ohms
R2—510 ohms
R4, R5, R32, R33, R77—680 ohms
R6—150 ohms, ½-watt
R7—1200 ohms
R8, R30, R44, R46—10,000 ohms
R9, R10, R26, R53—56 ohms
R11, R16, R17, R24, R25, R28, R60, R65, R87—75 ohms
R12, R15, R29, R34, R42, R52, R72, R79, R82, R86, R95—1000 ohms
R13, R47, R70, R93, R96—100 ohms
R14—3.9 ohms
R18–R21, R54, R73—470 ohms
R22, R23—120 ohms
R27—820 ohms
R31, R43, R69—220 ohms
R35, R37—22,000 ohms
R36—18,000 ohms
R38, R74, R94—100,000 ohms
R39, R40, R45, R92—4700 ohms
R41—unused
R48, R64—330 ohms
R49, R51, R88—2200 ohms
R50—120,000 ohms
R55, R56, R58, R62, R63—150 ohms, ½-watt
R57, R75—3300 ohms
R59, R61, R66, R68, R76—560 ohms
R67—43 ohms
R71—12,000 ohms
R78, R83, R84—0 ohms (jumper)
R80—47,000 ohms
R81—1500 ohms
R85—8200 ohms
R89, R90—2700 ohms
R91—68,000 ohms
R96—180 ohms, 1 watt
R97–R99, R101—unused
R100—5.6 ohms, 5 watts
R102, R104, R105, R107, R111, R112—5000 ohm trimmer potentiometer
R103—5000 ohm linear potentiometer
R106, R113—10,000 ohm trimmer potentiometer
R108—10,000 ohm linear potentiometer
R109—2000 ohm trimmer potentiometer
R110—5000 ohm linear potentiometer
R114—100,000 ohm trimmer potentiometer

Capacitors
C1–C5, C7, C8, C13–C18, C20, C21, C23, C24, C27, C42, C44, C50–C52, C61, C64, C65, C67—0.01 µF, ceramic disk
C6, C37, C41, C43, C54, C59, C66—unused
C9, C10, C63—33 pF, ceramic disk
C11, C12, C46, C53—0.001 µF, ceramic disk
C19—47 pF, silver mica
C22, C45, C49, C58, C60—10 µF, 25 volts, tantalum
C25, C56—47 µF, 16 volts, tantalum
C26, C48, C57, C59—0.22 µF, 30 volts, tantalum
C28—100 pF, ceramic disk
C29—56 pF, ceramic disk
C30—68 pF, ceramic disk
C31—300 pF, ceramic disk
C32—220 pF, ceramic disk
C33, C38, C62—100 µF, 16 volts, electrolytic
C34, C68—0.1 µF, ceramic disk
C35—470 µF, 16 volts, electrolytic
C36—10 pF, ceramic disk
C39—0.0047 µF, ceramic disk
C40—0.047 µF, ceramic disk
C47—5600 µF, 40 volts, electrolytic
C55—0.0022 µF, ceramic disk
C70—220 µF, 25 volts, electrolytic
C71—5–70 pF, variable
C72—2–20 pF, variable

Semiconductors
IC1—MWA120, hybrid small-signal amplifier
IC2—MC10116, triple differential line receiver
IC3, IC4—LM358, dual op-amp
IC5—MC1496, video detector
IC6—NE555, timer
IC7—NE592, video amplifier
IC8—NE564, phase-lock loop
IC9—7805, 5-volt regulator
IC10—7812, 12-volt regulator
IC11—7818, 18-volt regulator
Q1, Q2—BFR91
Q3, Q4, Q6—2N2222
Q5, Q7—BC328 or 2N3683
Q8—BC548 or ECG548
D1–D4—1N60
D5—1N752, 5.6-volt zener diode
D6—HP 5082-2800 or 1N6263 Schottky diode
D7—1S2075
D8–D11—1N4002
D12—BB119 tuning diode
LED1—standard green LED
LED2, LED3—standard red LED's

Other components
J1, J5—"F" connector
J2, J3, J4—RCA phono jack
J6—coaxial power input jack
TS1—4-position screw-terminal strip
L1, L5—10 µH
L2—0.33 µH, six turns on a ¼-inch form.
L3—100 µH
L4—2.7 µH
S1, S4—SPDT, toggle switch
S2, S3—DPDT, toggle switch
FL1—BO124 SAW filter
FL2—5–8 MHz block filter (Dick Smith L-1600)
M1—200 µA edge-reading meter
RF modulator
T1—18-volt AC power transformer

Note: the following are available from Dick Smith Electronics, Inc., P.O. Box 8021, Redwood City, CA, 94063: Complete kit of parts including case but no power transformer, #K-6316, $99.95 plus $4 shipping; SAW filter, #L-1620, $29.95; Case, #H-2507, $12.95; PC board, #H-7000, $29.95; 18-volt transformer, #M6672, $7.95;BFR91 transistor, #Z-1691, $1.19; BB119 diode, #Z-3070, $0.20; MWA120 RF amplifier, #Z-6095, $12.50; MC10116 ECL IC, #Z-6000, $0.79; HP5082-2800 Schottky Diode, #Z-3230, $2.00; 5–8—MHz filter, #L-1600, $3.95. Other individual parts, and complete satellite systems, are also available from Dick Smith. California residents please add 6.5% sales tax. Orders outside U.S. must include U.S. funds and add 15% of merchandise total for shipping.

Transistors Q1 and Q2 boost the filtered signal to drive both the limiter and the signal-strength meter circuit.

The signal-strength meter provides a relative indication of transponder strength. It can be used to fine-tune the position of the dish and the feedhorn for maximum signal strength. Trimmer potentiometer R107 sets the meter's full-scale deflection, and R114 sets the meter's sensitivity.

Amplitude limiting is provided by IC2, an MC10116 balanced ECL (*E*mitter *C*oupled *L*ogic) transceiver. That limiting removes amplitude-modulated components—impulse noise—from the 70-MHz signal. Two limited FM signals are provided by IC2's final stage at pins 2 and 3; those signals are 180 degrees out of phase with each other. Another 90 degrees of phase shift are provided by C71 and L2 before the signal from pin 3 of IC2 enters pin 4 of IC5. The signal from pin 2 of IC2 enters pin 8 of IC5 without further delay.

The 70-MHz carrier frequency is removed by IC5, an MC1496 balanced modulator-demodulator. That IC mixes the signals from pins 8 and 10 with those from pins 4 and 1 and removes the carrier frequency. The remaining signal, output on pin 6, is the baseband video signal. It contains all the video information as well as the audio sub-carrier.

The baseband video signal is buffered by Q4 to provide a low-impedance output. The inductors, resistors, and capacitors between R58 and C33 form a lowpass filter and a video de-emphasis filter. The filtered video is then amplified by IC7, an NE592 balanced-output video amplifier. The video level is set by R109, while the video polarity is set by a PC-board jumper connecting C34 either to pin 7 or pin 8 of IC7. For a normal video signal, connect C34 to pin 8.

Diode D6 is the clamp that traps out the 30-Hz dispersion waveform that is added to the video signal during uplinking. (That *dithering* technique helps to eliminate interference to terrestrial microwave communications.) Transistors Q6 and Q7 buffer the signal to provide a 75-ohm output with a one-volt p-p video level. The output of Q7 is also used to drive the RF modulator.

The baseband signal from Q4 is also amplified by Q5, and feeds a 5- to 8-MHz filter. The filtered signals are then routed to pin 6 of IC8, an NE564 phase-locked loop. That IC is used to lock in the audio subcarrier by varying the voltage on varactor diode D12. The tuning range (5.0 to 8.0 MHz) is set by C72, while front-panel SUB-CARRIER TUNING potentiometer R110 fine-tunes the audio sub-carrier.

Audio de-emphasis is provided by R80 and C55, and Q8 amplifies the signal to drive the RF modulator. A separate audio output is provided at jack J3. Trimmer potentiometers R111 and R112 set the narrow- and wide-reception bandwidths of the PLL, respectively.

As mentioned above, satellite-TV signals for the U.S. are broadcast in two polarities; horizontal and vertical. In order to receive signals of either polarity, we must have some way of rotating the antenna probe. The receiver offers a PULSE output at its rear-panel terminal strip TS1 for that purpose. When POLARITY switch S2 is toggled, the pulse width at the PULSE output changes, and that causes the motor-driven antenna probe (in the feedhorn) to rotate 90 degrees.

The control pulses are generated by IC6, an NE555 timer IC functioning as an astable multivibrator. Its pulses are output on pin 3; R47 protects the IC's output stage in case a short develops in the cable leading to the feedhorn. The SKEW control, R108, varies the pulse width for fine tuning of the received signal.

The pulse width of the output of the 555 circuit can vary from about 0.6 ms to 2.6 ms, which corresponds to a probe movement of about 160 degrees. Ideally, with SKEW control R108 centered, the output pulse width with S2 in its HORIZONTAL position would be 1.9 ms, and it would be 1.0 ms in its VERTICAL position. Then, each time the POLARITY switch is toggled, the probe will rotate 90 degrees. Because polarization may vary slightly from satellite to satellite, the front-panel POLARITY selection switch S2 is supplemented by the front-panel SKEW control (R108) for fine-tuning.

The RF modulator delivers a signal that is compatible with all standard TV's and VCR's to TV Channel 3 or 4. The modulator is crystal controlled, so no fine tuning is required.

Construction

Use of a PC board is strongly recommended; a foil pattern is presented in the "PC Service" section of this magazine.

Use the component-placement diagram in Fig. 3 and the photograph in Fig. 4 to assemble the board. When inserting parts in the PC board, work in numeric sequence, and check off each part as it is installed.

1—Beginning with resistor R1, insert all resistors in numerical order. R96 and R100 are not installed on the PC board.

2—Install the wire jumpers. Insulation should cover the entire exposed length of each jumper.

3—Install the trimmer potentiometers on the board, followed by the trimmer capacitors, and then the other capacitors. Carefully check the value of every part before mounting it. Be sure to orient all polarized capacitors correctly.

4—Install all diodes. Be careful to install them with the correct polarity, and use extra care in bending the leads on glass diodes.

5—Insert all IC sockets, making sure that pin one of every socket is oriented correctly. IC1 and FL1 should both be mounted flush to the board and soldered in. The leads of transistors Q1 and Q2 should be trimmed to a length of 2 mm, and those transistors should be mounted and soldered on the solder side of the board. The other transistors should be inserted from the top and soldered now. Leave ¼-inch of lead protruding above the board.

6—Voltage regulators IC10 and IC11 need heat sinks. Use heat-sink grease and mount them loosely to the heat sinks before inserting the assembly in the PC board. Align the legs of the regulators and the heat-sink tabs with the corresponding holes in the PC board, solder the regulators and heat sinks to the board, and tighten the screws. Install the 7805 regulator, IC9.

7—Mount POWER switch S3 and AFC switch S2 on the board and solder them.

8—Solder the two type-F connectors, J1 and J5, and the three RCA-type phono jacks, J2, J3 and J4, to the PC board.

9—Mount the RF Modulator on the board. Be sure that all four mounting tabs are flush, and then solder them to the board.

10—Mount and solder the inductors. Note that L4 is mounted vertically on the board. Install FL2 now.

11—Mount green POWER LED3 ½-inch above the board. It will be bent to fit into the front panel later.

(*Editor's note:* We recently heard from an experimenter who reported that the following modifications will improve performance: Remove R69 from the board. Replace R64 with a 220-ohm, ¼-watt unit. Add a 330-ohm, ¼-watt unit at the base of Q7.)

Front-panel assembly

At this point, all components should be installed except the IC's and the front- and rear-panel components. The front-panel layout is shown in Fig. 5.

1—Mount potentiometers R103, R108, and R110 to the front panel. Orient all three so that their terminals point down.

2—Viewing the panel from the rear, connect the center and right terminals of R108 together. Solder a seven-inch wire to all terminals except the right terminal of R108.

3—Mount switches S2 and S4. Solder six-inch wires to the three terminals on S4. Solder a seven-inch wire to each center terminal of S2; connect a short jumper between the upper-left and the lower-center terminals

4—Insert LED1 and LED2 into the appropriate holes in the front panel. Orient them so that their cathodes (the flat sides) are toward polarity-switch S2. Solder each cathode to the nearest lower-end terminal on that switch. Solder a seven-inch wire to each anode.

5—Solder ten inches of wire to each meter terminal. Mount the meter in the front panel.

Rear-panel assembly

1—Mount the terminal strip and AC-input jack J6 to the back panel.

2—Solder a jumper wire between the two ground terminals of TS1.

3—Solder R100 and the positive lead of C70 to the +5V terminal. Solder the minus lead of C70 to ground.

4—Solder one four-inch wire to the PULSE output terminal, another to one ground terminal, and another to the other end of R100. Solder a three-inch wire to the two bottom terminals of J6.

Final assembly

The component-placement diagram in Fig. 7 should be consulted while connecting the front- and rear-panel components to the PC board.

1—Insert and solder PC terminal pins (or short pieces of stiff wire) in all holes to which off-board components will be connected. Place the PC board in the cabinet, but do not screw it down yet.

2—Slide the front panel over the two PC-mounted switches, and then insert the front panel into the first slot of the cabinet. Carefully insert the green POWER LED into its hole.

3—Slide the rear panel over the connectors mounted at that end of the board, and then insert the rear panel into the last slot of the cabinet.

4—Insert and tighten the four mounting screws.

5—Connect all wires from the off-board components to the appropriate pins on the PC board. Doublecheck all connections.

6—Plug the transformer's output into J6, and then plug it into the wall.

7—Check the output of each regulator (IC9–IC11) for the correct voltage. Also, check the voltages at J5 (the +18V connector), at the +5V terminal strip, and at pin 8 of IC4 (+12V). The POWER LED and meter lamp should light up, and so should either LED1 or LED2, depending on the position of S2. Flip that switch to verify that the opposite LED lights up.

8—Turn off the receiver and unplug the transformer.

9—Insert all the ICs into their sockets. Be sure to orient them correctly, and make

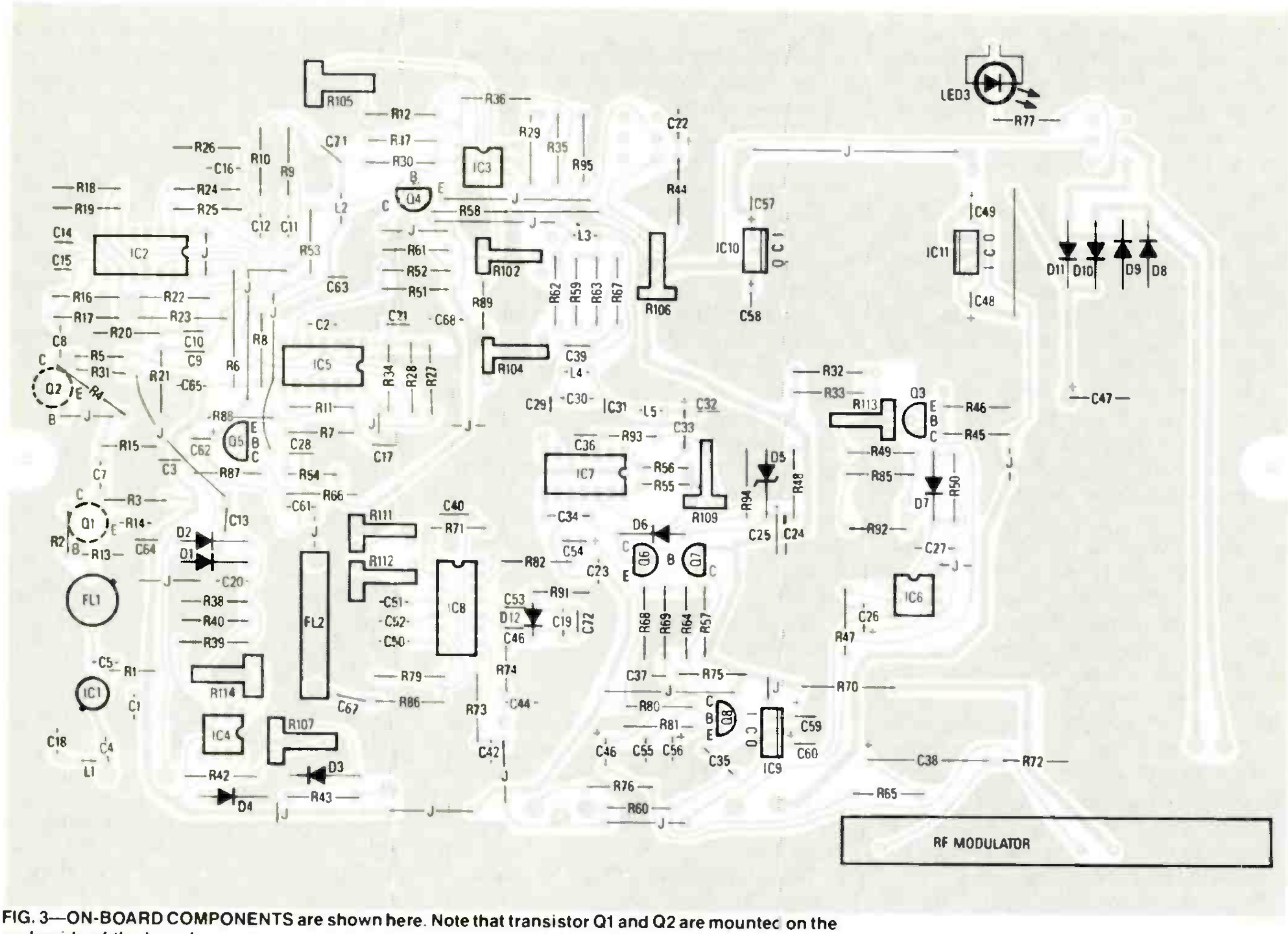


FIG. 3—ON-BOARD COMPONENTS are shown here. Note that transistor Q1 and Q2 are mountec on the underside of the board.

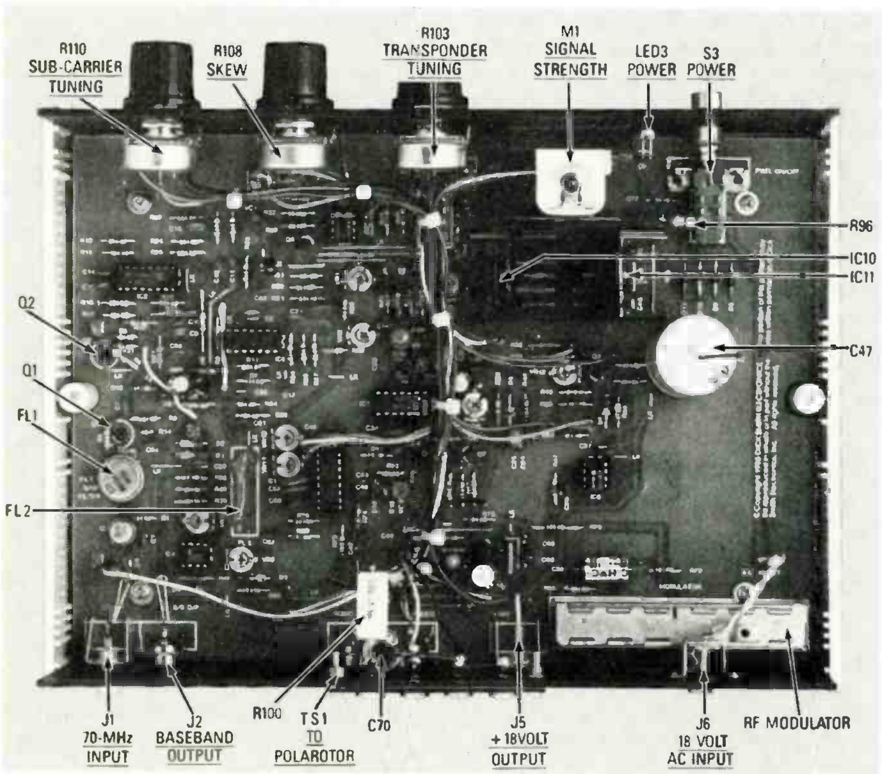


FIG. 4—THE COMPLETED PC BOARD. Be sure to route the interconnecting wires away from the voltage regulators.

sure all IC's are seated properly.

10—Route all wires down the center of the board. Be sure to leave clearance around the trimmer potentiometers, and route wires away from the regulators' heat sinks. Use wire ties to secure the wires.

11—Set each trimmer to the center of its range using a small screwdriver. Set the two trimmer capacitors so that the adjustment slot is parallel to the side walls of the cabinet.

12—Turn on the receiver and measure the total current drain. It should be about 400 ma.

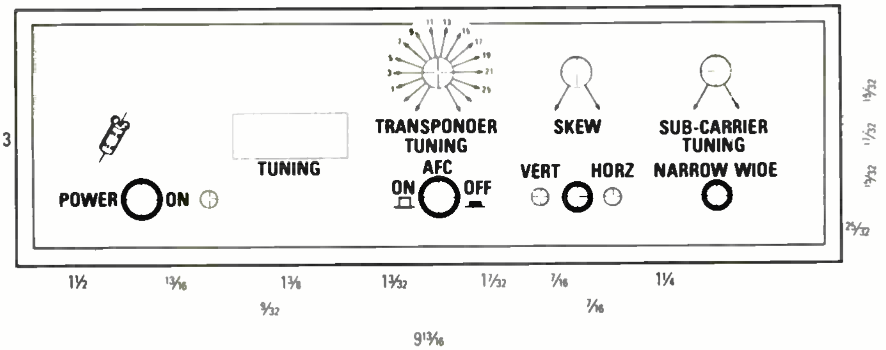
13—Measure the voltage at J1. The voltage should vary as R103, TRANSPONDER TUNING, is varied.

Aligning the polarizer

A friend or spouse may be helpful in completing the following alignment.

1—Connect the polarizer to the appropriate terminals on TS1. The red wire usually connects to +5V, black connects to ground, and white connects to the pulse output—but make sure your unit follows that convention. Center the SKEW control.

2—Turn on the receiver. Verify that the probe moves as POLARITY switch S2 is toggled. Mark the vertical probe position on the side of the polarizer. Move S2 to HORIZONTAL. Adjust R113 so that the probe is 90 degrees from its former position.



ALL DIMENSIONS IN INCHES

FIG. 5—FRONT-PANEL LAYOUT, with dimensions to fit the controls mounted to the PC board.

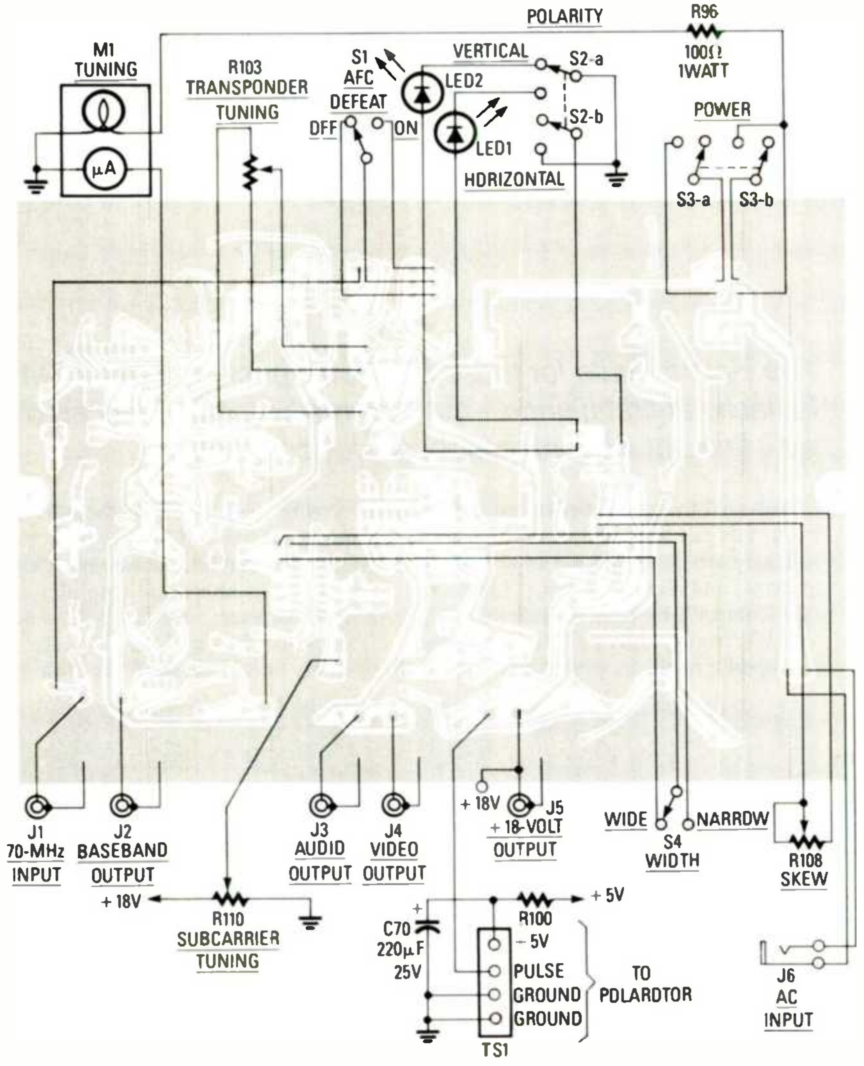


FIG. 6—FRONT- AND REAR-PANEL COMPONENTS are connected to the PC board as shown here.

Aligning the tuning control

The adjustments made now will be fine-tuned a little later.

1—Measure the voltage at pin 1 of IC3. Turn AFC on. Adjust R105 for exactly 3.0 volts DC. Turn AFC off. Adjust R106 for the same voltage.

2—Measure the voltage at J1. Set the TRANSPONDER TUNING control to line up with the "Channel 1" label on the front panel. The voltage should be set to the lowest voltage specified by the downconverter manufacturer. That is done by adjusting R104.

3—Set the TRANSPONDER TUNING control to Channel 24. Adjust R102 for the highest voltage needed by the downconverter.

Final check-out

The easiest way to check out and adjust the receiver is to use it on a system that is already working. Ideally, a friend or neighbor will allow you to hook up the receiver and downconverter for final testing. If that is not possible, then first you will have to get your dish aimed precisely at Galaxy 1. Instructions for doing that are usually given in the assembly instructions packed with the dish.

Next, the feedhorn, LNA and downconverter should be installed, and then cable should be run to the receiver. Do not use more than about 250 feet of cable between the downconverter and the receiver.

At this point you are ready to attach a TV (or a video monitor) and an audio amplifier to the receiver. CAUTION: Disconnect the receiver from the AC voltage source while hooking up everything. After everything is hooked up, reconnect the receiver to the AC voltage and follow these steps:

1—Turn on the receiver and adjust the TRANSPONDER TUNING control to receive a picture. Adjust the SKEW control and the POLARITY switch for the best picture.

2—Adjust C71 for maximum contrast in the picture. Gently compress and expand L2's coils slightly while observing the picture on several different channels. Adjust L2 for the best picture.

3—Adjust R109 for the best picture. Video level is controlled by that potentiometer, as is contrast. If it is adjusted to too high a value, a buzzing sound may be heard in the audio when lettering appears on the screen.

4—Set the SUBCARRIER TUNING control to the center position, and set the BANDWIDTH switch to WIDE. If no sound is heard, adjust R112 slightly. If nothing but noise is heard, adjust C72 until the audio comes through. That can be a "touchy" adjustment. Get it close, and then try fine-tuning the front-panel control. Once the sound is heard, readjust R112 for best audio.

5—Aim your dish at Satcom F-3, and tune in the appropriate transponder for either WTBS or WGN. Set the BANDWIDTH switch to NARROW, and then slowly turn the SUBCARRIER control counterclockwise from center. Several FM-radio programs should be heard. Adjust R111 for the best sound.

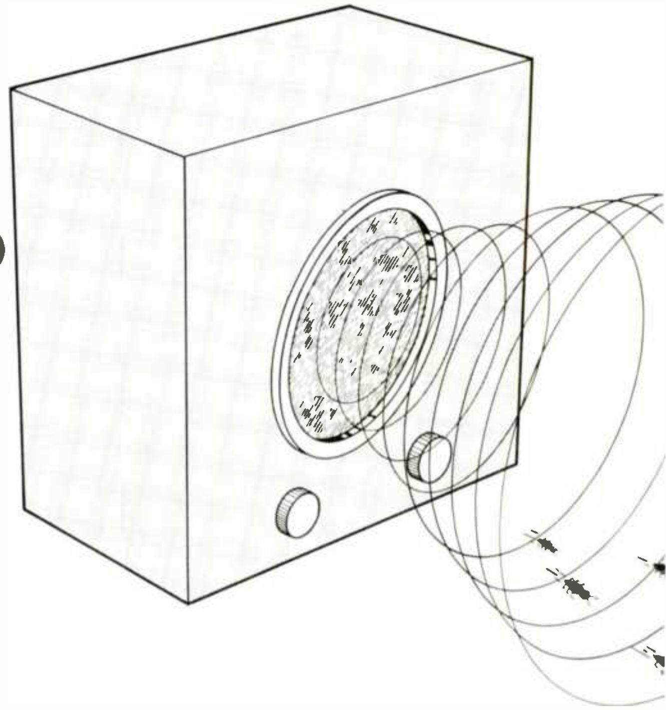
6—Adjust R107 for full-scale meter deflection when receiving the strongest station in your area.

7—Trimmers R102 and R104 may need to be adjusted slightly in order to make R103 correspond with the markings on the front panel. Set the TRANSPONDER TUNING control to the number of the lowest transponder channel received in your area and adjust R104 for best reception. Then set the panel control to the number of the highest channel in your area and adjust R102. Those adjustments will interact slightly, so go back and forth until both channels come in correctly. **R-E**

ALL ABOUT

ULTRASONIC PEST-REPELLERS

ROBERT F. SCOTT



The claims made for those ultrasonic pest repellers seem fantastic at first glance—but they really work. In this article, we'll find out what makes those devices "tick".

OVER THE YEARS, THERE HAVE BEEN many articles published that proclaimed that ultrasonics, either in the form of pulses or a sweep signal, can be used as an effective insect and rodent repellent. I've always been skeptical of such claims and placed them in the same category with those electronic devices claimed to prevent swallows from nesting on the courthouse roof and prevent pigeons from defiling the Stonewall Jackson statue on the town square. Nevertheless, I filed those articles away for investigation sometime in the future.

Last summer, my hunting and fishing club took possession of a farmhouse that had been abruptly abandoned about a year ago. The house was absolutely overrun with mice and roaches that were bold enough to scamper about in full daylight. We were at a loss as to how to get rid of them.

Ultrasonic pest repellents had begun to appear in mail-order advertising and our club president suggested that we try one. Those devices, according to the literature, generate a signal that sweeps over a frequency range of approximately 22 kHz to 65 kHz, develop sound pressures ranging from 115 to 152 dB, and repel pests in areas of 2500 to 3500 square feet. Power consumption is typically 2 to 4 watts. Prices range from $30.00 to $70.00, plus shipping.

At first, I scoffed at the suggestion that we purchase an ultransonic pest repeller, but agreed to try one since they were available for a 30-day trial and full refund. The $30.00 model was available from several sources under names that include Pest Control, Pest-Elim 1500, and Westronix. We ordered one and it came within a few days. It was shipped in a plain unmarked carton and we were surprised to find that it did not carry a trade name or model number. We installed it in the clubhouse. Within two weeks, mice and roaches were nowhere to be seen—even when lights were suddenly turned on in a dark room. Now, we consider the clubhouse completely free of pests. Not a sign of them: even in the darkest corners and crannies.

Now that the pest repeller had done its work, I began to speculate on its circuit. An early article on the use of ultrasonics in insect and rodent control ("Electronic Pest Control", by Lyman Greenlee, *Popular Electronics*, July 1972) indicated that the repeller needed a power amplifier delivering 16–20 watts in the ultrasonic region and special high-power tweeters. Certainly that little plastic box didn't contain a 20-watt power amplifier or high-power tweeters. Also, a 16–20-watt power amplifier drawing only 4 watts from a supply would be about as close to "per-

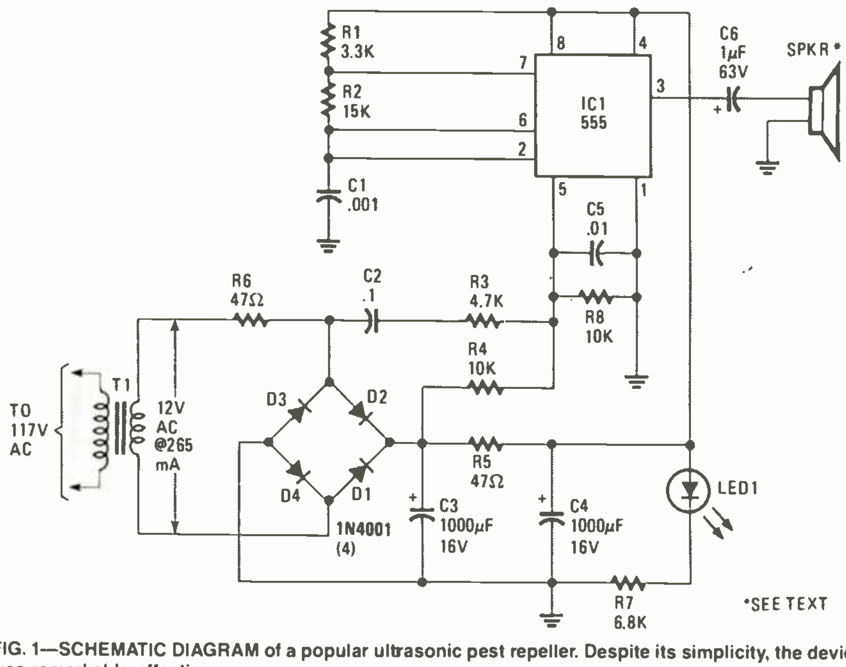


FIG. 1—SCHEMATIC DIAGRAM of a popular ultrasonic pest repeller. Despite its simplicity, the device was remarkable effective.

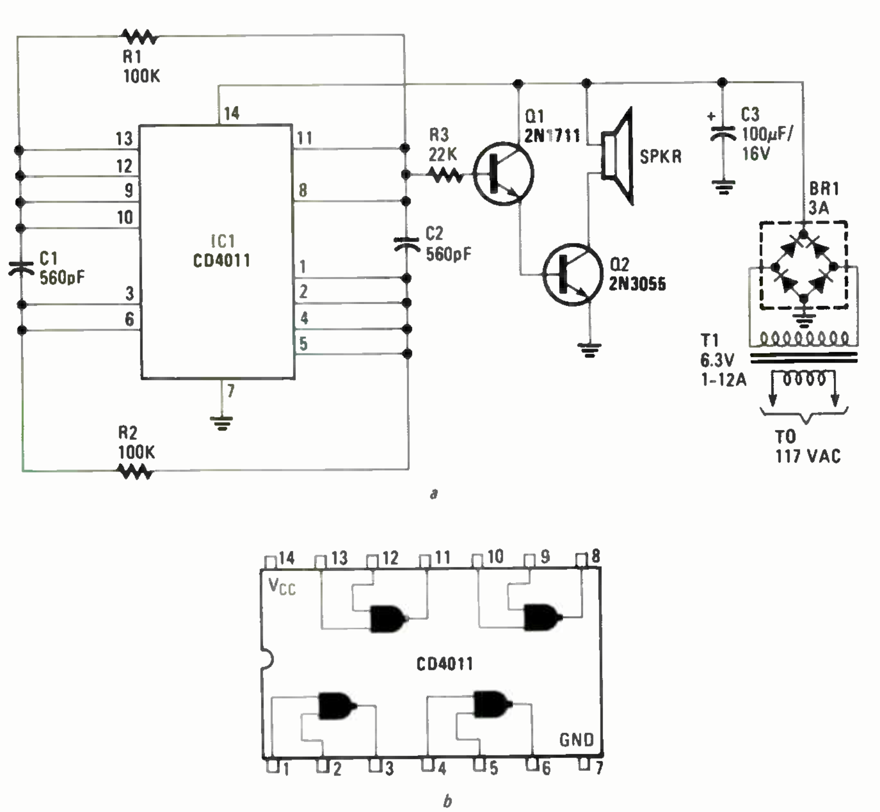


FIG. 2—THIS PEST REPELLER, of French design, is built around a CD4011 quad NAND gate. The schematic diagram is shown in *a*; a block diagram of the IC is shown in *b*.

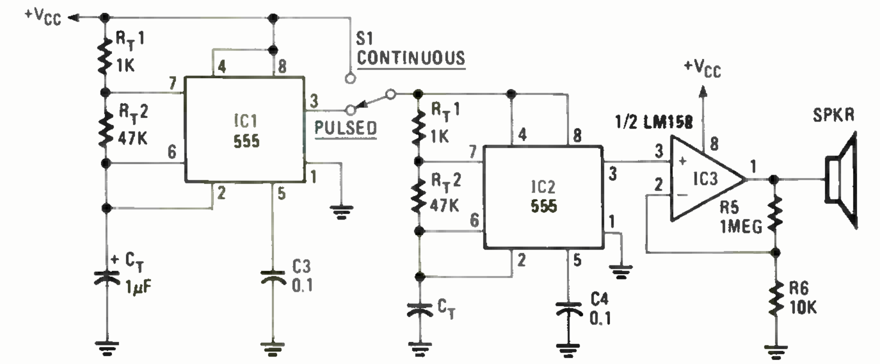


FIG. 3—THIS CIRCUIT IS ideal for experimenting with ultrasonic signals. It can supply either a pulsed or continuous output.

petual motion" as one can come. Thus, I couldn't wait to pry open the repeller's 6¼ × 4¼ × 1¼-inch plastic case and see what made it "tick".

Figure 1 is the circuit of the device we tested. We were quite surprised to find that the circuit was simply a 555 timer IC connected as a squarewave generator. Its base frequency is approximately 45 kHz, as determined by the values of R1, R2, and C1.

The 45-kHz "carrier" is frequency modulated by a modified trapizoidal voltage waveform applied to pin 5 of the 555 timer. That modulating voltage is developed by a network consisting of C2, R3, and R4 connected across one leg of the bridge rectifier. A check with an oscilloscope showed a sweep of approximately 20 kHz on each side of the base frequency. That sweep of from 25 kHz to 65 kHz is surprisingly close to the 22–65-kHz range specified in the ads. The speaker is a 2 inch piezoelectric tweeter.

How the French do it

The circuit in Fig. 2 is a pest repeller described in the French electronics magazine, *Le Haut Parleur*. In the article, the author claims that frequencies in the range of 20 to 40 kHz cause highly uncomfortable cavities to form in brain fluids and blood vessels of mice and insects, causing them to beat a hasty retreat. Radiated power levels can be as low as ⅓ watt.

Looking more closely at the circuit, a quad two-input NAND gate is connected as multivibrator operating at around 40 kHz. With the minimum of filtering used in the power supply, a residual 120-Hz sawtooth on the line from the power supply modulates the ultrasonic frequency. Two Darlington-connected NPN transistors provide some power amplification and drive for the speaker.

Circuit for experimenters

If you want to experiment with the effects of continuous or pulsed high-frequency signals, the circuit in Fig. 3 is ideal; it can provide either a continuous or pulsed output. It was developed by Signetics and described in *Electronic Products Magazine*.

Looking at the circuit, one 555 timer, IC2, generates the ultrasonic squarewave at a recommended 20 kHz. That signal can be supplied continuously or pulsed on and off by a second 555, IC1.

Experimenting with frequency and duty cycle is easy. Duty cycle is the "on" time compared to the total period, and can be set from slightly above 50% to almost 100%. In the astable multivibrator circuit, the duty cycle is set by the timing resistors, R_T1 and R_T2, and is equal to $R_T1 + (R_T2/R_T1) + 2R_T2$.

The on time is close to 100% when R_T1 is chosen to be as small as practical while limiting the current through the discharge transistor to the maximum specified in the data sheet. (The discharge transistor, which is on-board the 555, is an open-collector NPN device with the collector going to pin 7 and the emitter to ground at pin 1. The maximum current through it varies with different manufacturers so you should check the maker's data sheet to be sure.)

If you want a duty cycle of less than 50%, connect a general-purpose silicon diode such as the 1N914 across R_T2 with its anode at pin 7 and cathode at pin 6. That effectively shorts R_T2 while timing capacitor C_T is charging, and the duty cycle is now $(R_T2/R_T1) + R_T2$ and it can be varied from around 0 to nearly 100%. The frequency of the squarewave generator can be found from $1.44/C_T(R_T1 + 2R_T2)$, where resistance is in megohms and capacitance in microfarads.

If you want to vary the duty cycle of the oscillator while keeping the frequency constant, use the basic circuit shown in Fig. 4.

In that circuit, a single potentiometer is used for the two timing resistors. In that scheme, it is possible to set the value of one of the two "timing resistors" to zero. As that is undesirable, two resistors, R1 and R2, have been added to set minimum values for those timing resistors.

Use the basic circuit shown in Fig. 5 when you want to vary frequency while keeping the duty cycle constant at approximately 50%. The variable element used in that circuit, R_T-a and R_T-b, is a two-gang linear potentiometer. Note that the value of the two variable elements are

continued on page 138

BUILD THIS

SEE-IN-THE-DARK

VIEWER

ROBERT GROSSBLATT

"See in the dark" with this easy-to-build infrared viewer!

THE PHRASE "SEEING IN THE DARK" is a misleading one. With the possible exception of mystics and mutants, when the lights go out, we all walk into walls. Being able to see in the dark all depends on what you mean by "dark." The human eye is only sensitive to a very narrow band of the electromagnetic spectrum, as shown in Fig. 1. Figure 2 shows the eye's relative sensitivity to wavelengths in that narrow band.

The infrared portion of the electromagnetic spectrum is just below visible light and extends from about 700 to well past 10,000 millimicrons. The human eye is normally insensitive to electromagnetic radiation in that region. In order to produce a visible image using infrared light, then, we need a device that's both sensitive to infrared and able to translate an infrared image into one that the human eye can see. One such device is the RCA 6032 image converter tube, and that tube is the heart of the infrared viewer that we'll show you how to build.

The 6032 can be thought of as being divided into two parts. The front end is a photosensitive cathode that responds to infrared radiation in the range of 500 to 1200 millimicrons. Whatever image is focused on the cathode is reversed left-to-right and passed on to the second part of the tube. That is a small fluorescent screen on which the visible image is formed. Focusing the image on the screen is done electrostatically—a voltage is applied to the focus ring at the tube's center and controls the convergence and divergence of the electrons being aimed at the screen's phosphor. That is similar to the way the electron gun is focused in a television set.

Building the viewer

The schematic of our viewer is shown in Fig. 3. As you can see, the circuit's only job is to produce the voltages that the image converter tube needs to operate. Before we start talking about how the circuit works and what's needed to actually build it, there are two things that have to be said.

CAUTION! The tube needs about 12,000 volts to operate, and 12,000 volts is a very serious amount of voltage! Because of that, the utmost care must be observed when working with this circuit. Any carelessness is dangerous, and could very possibly be fatal. BE VERY, VERY CAREFUL!

That caution should be taken seriously, even though the circuit is powered by a 9-volt battery. That's because our power supply is capable of producing as much as 15,000 volts from a fresh battery. Also, although the tube only needs a handful of microamps to operate, the supply can produce over 200 microamps. There's a world of difference between 200 microamps at 10 volts and 200 microamps at 15,000 volts! Once again, 15,000 volts can be lethal, even if the current is negligible. Be careful!

Secondly, the tube itself is made of glass and, just as any other type of electronic tube, it contains a vacuum. Although the glass is thick and the tube is strong, the tube will implode if punctured. Now, flying glass from such an occurrence is bad enough, but the phosphor on the screen can do you a lot of damage if it gets into a cut. To avoid any problems, handle the tube carefully and when you solder the high-voltage leads on the tube, make sure the iron is in contact with the tube for as short a time as possible. Tin the wire ahead of time and *never—repeat, never—* solder near the tube's glass seals.

Keeping those warnings in mind, let's take a look at the circuit.

The first stage of the power supply is an oscillator formed basically by Q1, Q2, and part of the primary of T1. Resistor R1 keeps the circuit unbalanced so that oscillation will start when power is first applied. The base current for the transistors is produced by induction in T1 and is limited by R2. The switching action of the transistors causes the induced voltage in T1 to switch polarity and that alternatively turns on Q1 and Q2 in turn. The two diodes, D1 and D2, are steering diodes for the base current.

When S1 is closed, current flows through R1 and T1. The base drive for the transistors comes from T1's stand-alone winding. Because the two transistors are being driven out of phase, the circuit begins to oscillate. That causes an induced voltage to appear across T1's secondary. How great that voltage will be depends on how much voltage is available from the battery. Assuming that the battery is between 7 and 9 volts, the induced voltage on T1's secondary will be between 200 and 300 volts.

That voltage is rectified by the full-wave bridge made from diodes D3 to D6. Capacitor C2 is charged through D7 and R3, setting the stage for the next part of the circuit's operation. Transistor Q3 is the center of a timing circuit with an R-C constant determined by the values of R6, R7, and C3. The 15-microsecond pulse produced by that part of the circuit fires SCR1, and causes C2 to discharge, inducing a high-voltage pulse in the secondary of T2. That voltage is rectified by D9.

The voltage produced by the discharge of C2 is boosted by the inductance of T2's primary and that negative overshoot causes the SCR to turn off. As soon as the SCR turns off, the whole process starts all over again.

The image-converter tube requires a high voltage in order to focus the image on the fluorescent screen. That voltage is applied via a voltage-divider circuit made up of R8 and R9. Don't forget that by the time power gets up to the tube, we're talking about some 12,000 volts at fairly high peak-current values. The values for those two resistors are extremely high because only flea power is needed at the focus ring of the tube. Excessive current can destroy the tube, so the resistor values are probably higher than you've ever seen before.

Getting the tube to produce a sharp image is a matter of providing the right voltage at the focusing ring. The value of 2000 megohms for R9 can be considered a final value, but the voltage will have to be adjusted by daisy-chaining resistors together to form R8. A value of 200 megohms is a good starting point; the optimum value, which varies from tube to tube, will be within 15% of that.

If the operation of the power supply seems familiar to you, it's probably because the same basic principles are used in the design of most automobile capacitive discharge systems. The same sort of pulsed high voltage is needed to make the spark plugs fire. And if you've ever fooled around under the hood of a car, you know that you can be knocked over backward by the juice at the plugs. Once again: **BE CAREFUL WHEN YOU ARE WORKING WITH THE HIGH VOLTAGES INVOLVED IN THIS PROJECT.**

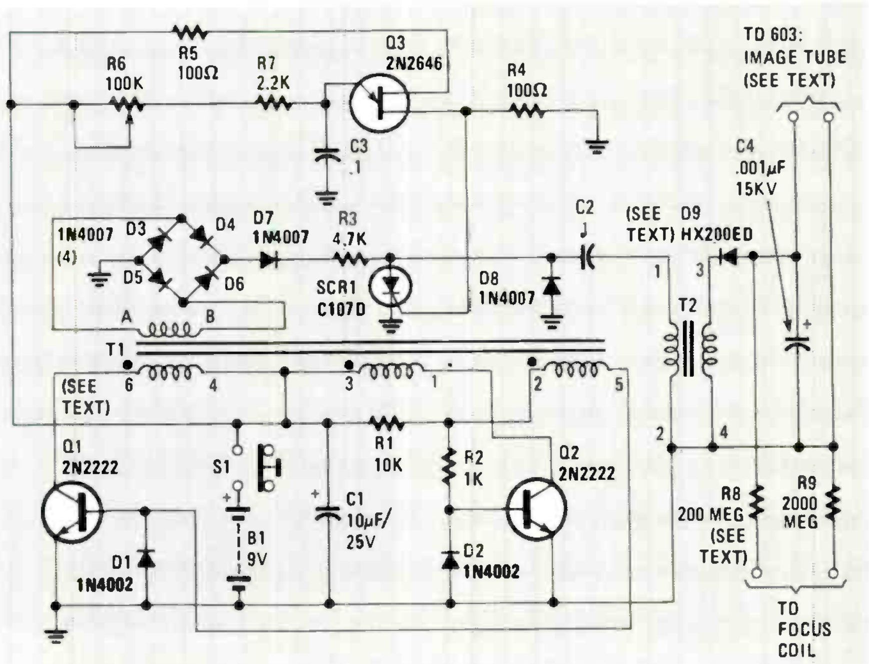


FIG. 3—THIS POWER SUPPLY can produce up to 15,000 volts from a single 9-volt nickel-cadmium battery.

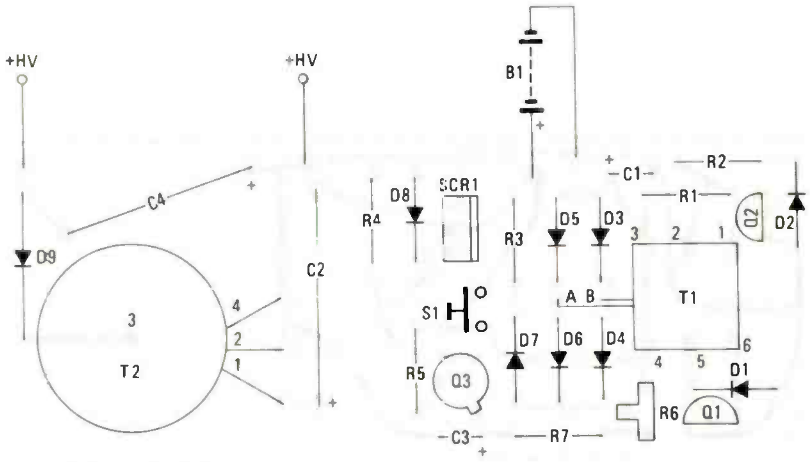


FIG. 4—IF YOU CHOOSE TO use a PC board, this parts-placement diagram should be followed.

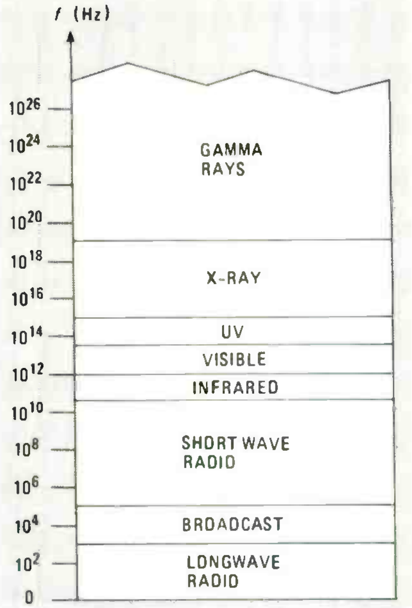


FIG. 1—VISIBLE LIGHT takes up only a small slice of the electromagnetic spectrum.

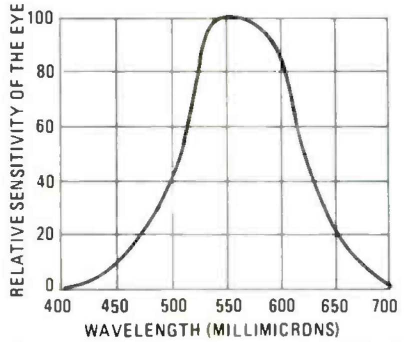


FIG. 2—THE EYE IS most sensitive to light in the range of 550 millimicrons.

Construction

Building the circuit for the infrared viewer is relatively straightforward and can be done on either a perfboard or PC board. We recommend using a PC board; an appropriate pattern is provided in our "PC Service" section, on page 78, and the corresponding parts-placement diagram in Fig. 4.

Whatever method you choose, because we're dealing with high voltages, there are several considerations that are different from a low-voltage circuit:

- All solder joints must be clean and shiny. Because of the voltages involved, anything less than a perfect joint will cause arcing.
- Leads must be absolutely cut as short as possible.
- All the components on the board, and especially those that follow T1, should be locked in position with paraffin, varnish, or high-voltage putty.

The first step is to mount and solder the components onto the board. Do not, however, mount the high-voltage portion of the circuit (T2 and the circuitry on the secondary side of that transformer). Before building that part of the circuit, you need to verify that the balance of the project is operating correctly. When you mount the components on the board, pay attention to the polarities of the diodes and capacitors. Make sure that the transistors are correctly oriented and the transformer leads are properly identified. Do your soldering only when you're sure that everything is correct.

The next step is to verify that everything to this point is operating correctly. Connect the leads from an ohmmeter to the battery clips and press S1. That is an easy way to make sure you don't have a short across the power supply. If that checks out fine, connect the power leads to a 6-volt supply and measure D7's anode voltage. You should see about 175 volts there, and the drain on the 6-volt supply should be no more than 75 mA. *Be very cautious* when you're taking those measurements. It may seem that 175 volts is a long way from 15,000 volts, but that voltage can still do a bit of damage.

Once everything checks out, you can mount and wire the rest of the circuit. If you don't get the proper readings, check your connections on the board again. The circuit is simple enough for you to be able to find your mistake without too much irritation.

Take the high-voltage leads and tape them down so that they're about a quarter of an inch apart. Connect the circuit to the 6-volt source again and you should see sparking at the output. You have to adjust R6 for the minimum spark rate. If you watch the current draw, you should see it drop as the sparking rate is reduced.

Once again a word of caution. Anytime you're adjusting a circuit that produces high voltage, you want to be absolutely sure to isolate yourself from the board. That means that a metal-bladed screwdriver, or anything else metal, for that matter, to make adjustments is a definite no-no. And contrary to popular belief, you don't want to use a wooden anything either. High voltages do weird things and that includes traveling through anything that is even the least bit conductive. Wood is porous, can absorb moisture from the air; the result can very well be you lying on the floor!

Once you've finished assembling the high voltage supply and you're sure it works, you're ready to tackle the image converter tube. But just as there was for the power supply, there are some precautions to keep in mind for this part of the assembly as well.

- When you're soldering connections to the various rings on the tube, do it as quickly as possible. Tin the wires before you solder the connections. If you apply too much heat for too long, you'll destroy the glass-to-metal seals on the tube.
- The tube is made of glass and contains a vacuum. The weakest points on the tube are at the small areas where the glass was sealed after the tube was assembled. **Keep your iron and any solder away from the glass in general and those seals in particular.** The glass can implode and the phosphor coating on the screen can cause you a great deal of trouble.

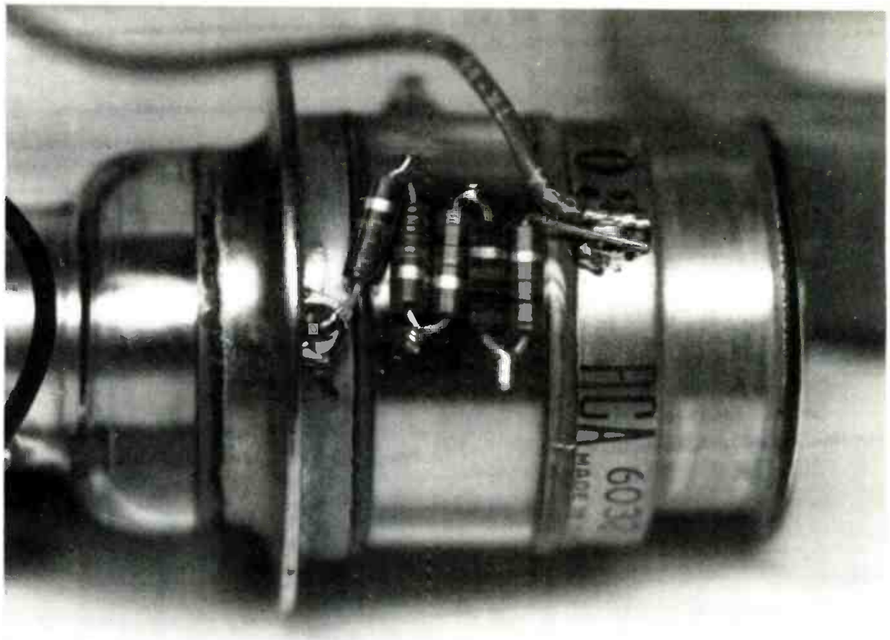


FIG. 5—SEVERAL RESISTORS will need to be daisy-chained to obtain the value needed for R8.

With those precautions in mind, solder R9 between the focus ring and the ring surrounding the fluorescent screen. Once you've done that, solder short pieces of wire to the ring surrounding the objective end of the tube and another point on the focus ring. Temporarily connect R8 across those pieces of wire as well as the high voltage leads from the power supply. Make sure that the lead coming from the D9-C4 junction on the power supply board is connected to the R8/objective end of the imaging tube and the other lead is connected both to ground on the board and the R9/eyepiece end of the tube.

When you've made sure that everything is hooked up properly, apply power to the circuit and you should see the phosphor at the eyepiece end of the tube glow with a green light. Turn off the power and fasten a piece of window screening flush against the objective end of the tube. Re-apply power and you should see an image of the screening on the phosphor screen. Your next step is to adjust the value of R8 to make the image as sharp as possible. Varying the voltage at the focusing ring changes the electrostatic focus of the tube. You'll have to experiment with a number of resistor combinations to find the value that produces the sharpest focus. As we said before, 200 megohms is the nominal value and the correct value for your tube is probably within plus or minus 15 percent of that.

Once you've daisy chained the resistors together and soldered them to the imaging tube (see Fig. 5), you have only one more final test to do before you can call it a wrap. Turn out the lights and apply power to the circuit again. What you're looking for here is evidence of high voltage leaks. Those will show up as small sparks or "corona." Note the places where they show up and turn the power off. Wait a second or so for the circuit to discharge, then insulate those areas with high-voltage putty.

Believe it or not, once you've made sure that the focus is as sharp as you can make it, (or is at least acceptable to you), and there's no evidence of corona, the project is completed.

Now we come to the question of the case. You need a focusing lens in front of the tube and a viewing lens at the rear. In order for the front lens to focus a sharp image on the tube's objective, both the tube and the lens have to be on the same axis. And the same conditions apply to the

MEASURING WAVELENGTH

Whenever you're talking about the electromagnetic spectrum, some confusion can arise over the units used to refer to the wavelength of the radiation.

As you move up the spectrum from DC toward daylight, the frequency of the radiation will increase and the wavelength will decrease. Those two measurements are related by "c," the speed of light through: $\lambda = K(f/c)$

where λ is the wavelength, f is the frequency in Hertz, c is the speed of light, and K is a constant determined by the medium through which the radiation is travelling.

Although you can refer to the wavelength in meters, by the time you get up to the visible part of the spectrum, the wavelengths are pretty small. Green light, for example, has a wavelength of about 550×10^{-9} meters. The two most common units of measurement for the upper reaches of the spectrum are the millimicron (10^{-9} meters) and the Angstrom (10^{-10} meters). The latter is named after the 19th-century Swedish physicist A. J. Angstrom.

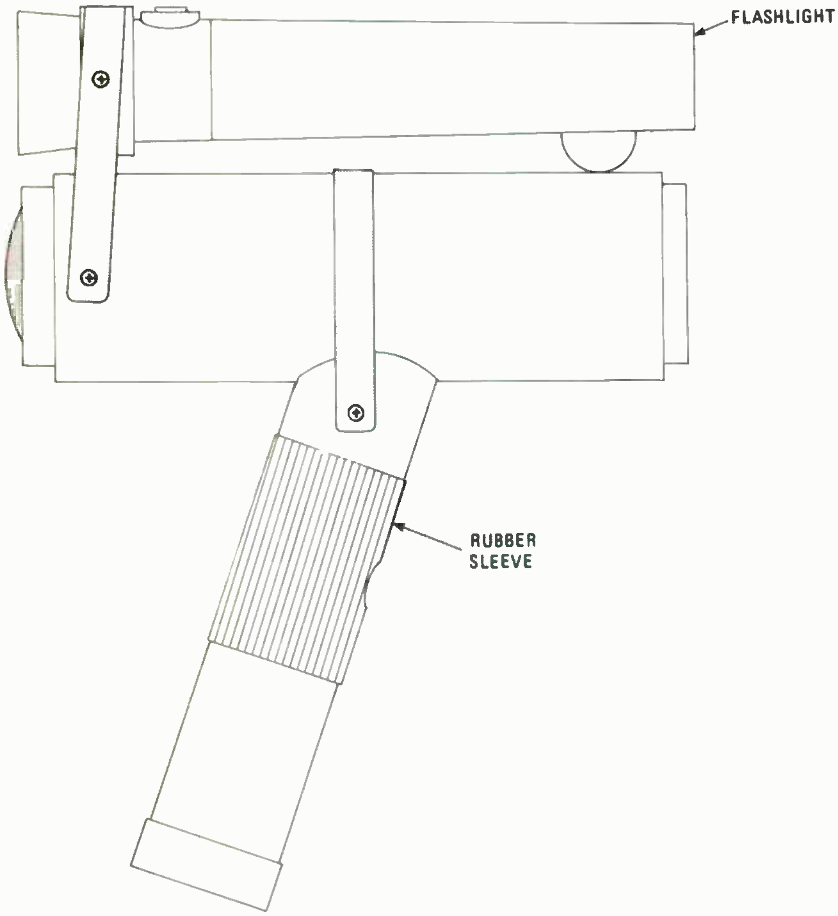


FIG. 6—THOUGH THE CASE is not critical, here is one that works well. The flashlight at the top is fitted with an infrared filter for use as a source of infrared light.

viewing lens at the rear. The easiest solution to the problem is to use a piece of tubing to hold the whole assembly. PVC tubing is perfect for that purpose.

A length of 2½-inch diameter PVC will hold the imaging tube if you shim the ends with 2⅛-inch tubing. The same 2⅛-inch tubing can also be used to mount the front and rear lenses. Use set screws to hold the 2⅛-inch tubes inside the main PVC enclosure.

One appropriate case is shown in Fig. 6. The optics in that unit are encased as just described. The PVC handle contains the power supply board and the battery. Once the board is mounted, cut a hole out over S1 so that it can be conveniently pressed. To prevent accidental contact with the board, slide a flexible rubber sheath (a section from on old bicycle tire inner tube will do) over the handle so that the hole is covered.

Note that there is nothing critical about the case. When designing and building a case for your unit, the only precaution is to make sure that no extraneous light can leak inside the tube, because that will degrade the quality of the image. Black tape or putty can take care of any light leaks.

Once you have the viewer assembled, you're ready to explore the world of infrared light. It's interesting, and somehow reassuring, to watch a television remote control. Yes, they really do put out bright flashes of previously invisible infrared. If you put an infrared filter in front of a flashlight, you'll be able to see in the dark by using the flashlight and peering through the viewer. (You'll note that the unit shown has such a flashlight mounted on it. That flashlight serves as an infrared light source. Also note that once the infrared filter is in place; the light emitted by the flashlight can not be seen by the naked eye.) Deep infrared filters are expensive but a piece of unexposed but developed Kodachrome will do almost as well. Use the ends that come back in the box along with your developed slides.

Infrared energy is also produced by heat. You can prove that by getting a steam iron nice and hot and putting it next to a piece of newspaper. Turn out the lights, look through the viewer, and you'll be able to read by the heat of the iron.

As to the quality of the image you see using the viewer, there are two limiting factors. Those are the "brightness" of the infrared source, and the quality of the optics used.

Turning first to the brightness of the source, the unit shown uses a common flashlight as described. That should be sufficient in most cases. If not, a brighter source of light can be substituted, as long as an infrared filter is used as outlined above.

The optics (lenses) are much more critical. The standard optics supplied with the kit offered by the source mentioned in the Parts List are adequate for most hobbyist applications. If you require images with more sharpness and clarity, however, you will need to use higher quality, and more expensive lenses. Such lenses are also available from the source given in the Parts List.

The uses of infrared imaging are endless and eye opening. If you want to find out more about the subject, Kodak publishes a wonderful booklet called "Applied Infra Red Photography." Write to **Kodak**, Consumer Markets Division, Rochester, NY 14650. **R-E**

PARTS LIST

All resistors ¼ watt, 10% unless noted
R1—10,000 ohms
R2—1000 ohms
R3—4700 ohms
R4, R5—100 ohms
R6—100,000 ohms, potentiometer
R7—2200 ohms
R8—200 megohms, see text
R9—2000 megohms, see text
Capacitors
C1—10μF, 25 volts, electrolytic
C2—1μF, 400 volts, electrolytic
C3—1μF, 25 volts, electrolytic
C4—.001μF, 15 kV, ceramic
Semiconductors
Q1, Q2—2N2222 NPN transistor
Q3—2N2646 FET transistor
D1, D2—1N4002
D3–D8—1N4007
D9—MX200EP, 20-kV diode
SCR1—C107D
Other components
B1—9-volt nickel cadmium battery
S1—SPST, momentary pushbutton, normally open
T1—12 to 400 volts, 10kHz switching transformer
T2—11 kV pulse transformer, 400-volt primary
Miscellaneous: 6032 image tube (RCA), PC board, PVC tubing for case, focusing and viewing lenses, battery clip, flashlight, wire, solder, etc.

The following are available from Information Unlimited, PO Box 716, Amherst, NH 03031: Complete kit, including case and basic lenses, but minus the 6032 image tube, $99.50; 6032 image tube, $49.50; assembled and tested unit $199.50; power board kit $34.50; assembled power board, $49.40; T1 alone, $14.50; T2 alone, $15.50; D9 alone, $2.50; C4 alone, $3.00; optional 75mm telephoto focusing lens with iris adjustment and C-mount, $125.00; optional 50mm wide-angle focusing lens with C-mount, $95.00.

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EH87

If you've been wondering if you can obtain IBM compatibility for a reasonable price, the answer is that you can. We'll show you how.

ELLIOTT S. KANTER

FOR BETTER OR FOR WORSE, THE IBM PC HAS BECOME THE *DE FACTO* standard personal computer. Of course, like all computers, the PC has its shortcomings. But its most serious problem is its expense. There is a way around that problem, however, and **Radio-Electronics** will show you that way. We'll show you how you can put together a PC-compatible computer using parts available from HiTech International. We'll explain how the computer works, and we'll review its performance.

HiTech International, whose computer we'll be assembling, is a supplier of IBM PC XT-compatible motherboards (system boards) and other accessories. The best part about the HiTech computer is that even a novice at electronics construction can assemble his own computer at considerably less cost than IBM's offering.

PC Compatible Computer

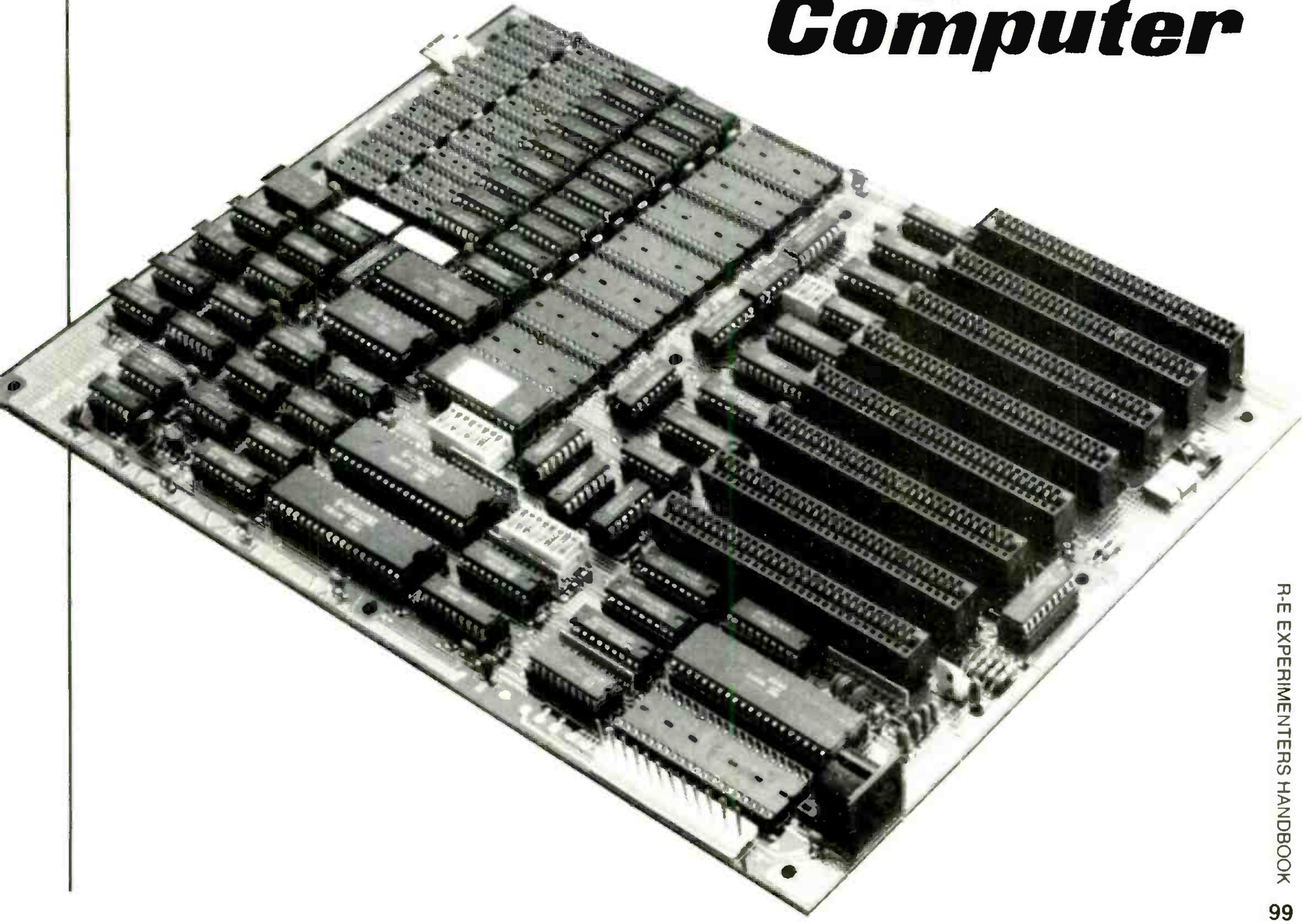


TABLE 1
IBM PC XT SPECIFICATIONS

Microprocessor:	Intel 8088 (4.77 MHz) with socket for addition of an 8087 math co-processor.
Memory:	ROM: 40K, includes BASIC interpreter. RAM: Either 128K or 256K onboard, expandable up to 640 KB with a memory- expansion card
Keyboard:	83-keys with 10 function keys, numeric/cursor keypad, adjustable typing angle, and detachable 6-foot coiled cable
Mass Storage:	10 MB fixed/hard disk, 360 KB double-sided/double density 5¼-inch disk drive
Expansion:	Eight expansion slots
Software:	Diagnostics, *Microsoft* cassette BASIC interpreter in ROM
Operating System:	PC DOS 2.1 (with advanced disk BASIC)
Size: 5½ × 20 × 16 inches	
Weight:	32 pounds
Cost:	$3895
Warranty:	90 Days.

TABLE 2.

BASIC IBM PC XT

Part No.	Item	Price
8529254	PC XT motherboard with 128K RAM	$750.00
8529247	130-watt power supply	$390.00
8529161	Base Assy (case bottom)	$ 86.00
852963	Bezel Assy (case front)	$ 41.50
8529209	Top Cover (case)	$ 50.50
	Keyboard assembly (complete)	$270.00
	64K memory modules (2 required)	$200.00(2)
	TOTAL:	$1788.00

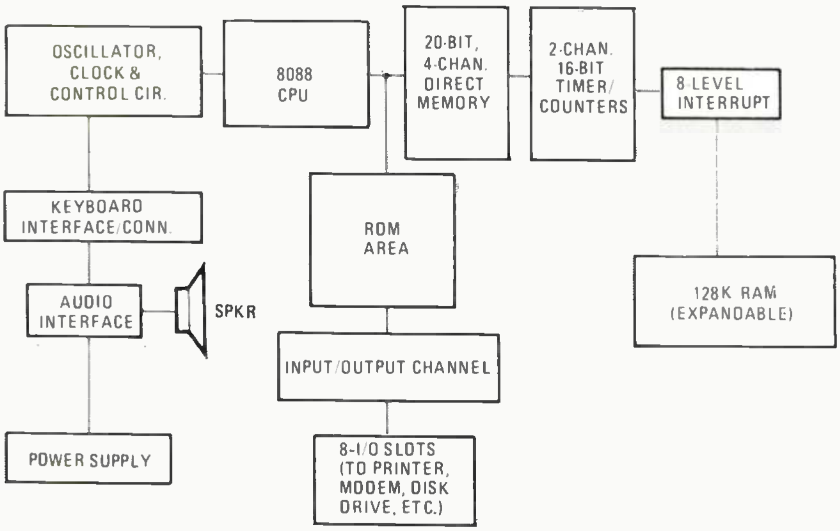


FIG. 1—A BLOCK DIAGRAM of the IBM PC XT shows the "musts" for a personal/business computer. The HiTech PC also has the same block diagram.

Many of HiTech's customers are service centers who buy the system or motherboard to use as running spares for PC XT's brought in for repair. The boards are the same size as IBM's, and—with the exception of the lack of BASIC in ROM—have the same form and function as that of the PC XT board. The basic IBM PC XT can not tell the difference between an IBM board or a HiTech board. And, unless you run the *Advanced Diagnostics Program Diskette* from IBM, neither will you. The discernible difference between the two boards appears as an error message which translates to "Hey, there's no BASIC in the ROM..."

Building by subassembly

In this article, we won't show you how to put together a computer piece-by-piece. (For example, the motherboard is regarded as a single component.) Instead, we'll show you how to build it subassembly-by-subassembly. We'll build the system in stages so that it can be expanded when the need for more functions makes it necessary (or when the cash flow permits). But we're getting a little bit ahead of ourselves. Let's talk more about the IBM PC before we talk about how to assemble a PC-compatible computer.

A brief history of the PC

For many years, the terms "personal computer" and "PC" have been applied to small, limited-use microcomputers which, because of their limited power, have been relegated to home rather than business use. That changed when computer-giant IBM unleashed a small multifunction microcomputer that has become the *de facto* definition for PC. Some three years ago, the IBM PC was introduced to the marketplace and the public's perception of computers changed. More computers were found in small and large offices and in the home. While there were already a number of "business-quality" microcomputers or PC's available, the magic letters IBM tended to make then more acceptable.

There were many other fine companies producing computers. But when the sales figures for any given period are compared, it's obvious that, by numbers alone, IBM was literally taking over the market. Even so, the new entry to the scene was not without its detractors. The most common complaint was (and still is) about the keyboard. The company that pioneered a standard in typewriter keyboards with the *Selectric* really missed the boat with the PC. Some keys are located in illogical positions, and the feel is not comfortable (although you *can* get used to it). Others complained that IBM could have gone with a more advanced microprocessor, and that the machine was too slow. Despite those, and other, complaints, the sales of PC's continued.

In the business world, if a product sells it's a success! And success breeds imitation and—as the PC imitations came to be known—clones. The buzz words "IBM compatible" became a company's ticket to bigger sales. Many manufacturers did

TABLE 3.
BASIC PC XT HITECH INTERNATIONAL

PC XT motherboard with 128K RAM	$525.00
Power supply, 130 watts	$175.00
Case (complete)	$150.00
Keyboard (complete)	$150.00
RAM Each 64K 2 required(3)	$ 50.00
Total:	$1050.00

TABLE 4
HITECH PC XT SPECIFICATIONS

Microprocessor:	Intel 8088 (4.77 MHz) with socket for addition of an 8087 math co-processor.
Memory:	ROM: 8K implemented (can be expanded by user to 40K) RAM: Either 128K or 256K onboard, expandable up to 640K with a memory-expansion card
Keyboard:	Enhanced Key Tronic 5150 PC. 83-keys with 10 function keys, numeric/cursor keypad, adjustable typing angle and detachable 6-foot coiled cable
Mass Storage:	10 MB fixed/hard disk, 360 KB double sided/double density 5¼-inch disk drive
Expansion:	Eight expansion slots
Software:	Diagnostics, supports DISK BASIC
Operating System:	PC DOS 2.1 (with advanced disk BASIC)
Size:	5½ × 20 × 16 inches
Weight	32 pounds
Cost:	$2,454.00
Warranty:	1 Year.

TABLE 5
HITECH PC XT + PARTS LIST

Part No.	Description	Price
RE-PCB W/IC	Motherboard with 128K RAM	$525.00
RE-PS-130	130-watt power supply	175.00
RE-ROM	BIOS ROM	35.00
RE-CASE	Case (complete)	150.00
RE-5150	enhanced keyboard	150.00
RE-MON/DIS	RGB video card	175.00
RE-DISK DR.	Teac 360K disk drive	125.00
RE-CTRL-A	Disk controller/parallel port	175.00
RE-HARD DISK	10 megabyte drive with controller	650.00
RE-YAD	Y Adapter (to attatch two drives)	5.00
	Total:	2165.00

everything and anything they could to make their offering the same in form and function as the IBM PC. A few companies made such perfect duplicates that they found themselves in legal difficulties with IBM. Others modified their product and qualified their "compatiblity" by stating it would "...run *most* of the vast library of business applications packages." That approach was perhaps the most prudent for the company which did not want to earn the attention of the lawyers in residence at IBM. There even were a few computers that *did* achieve compatibility without paying the price of legal hassles and the like. The system from HiTech International, which we are examining in this article, is one of them.

While achieving compatibility is important for the computer company, the bottom line is: Can the average small-business person afford the end product? While the IBM PC appeared on the surface to offer quite a "bang for the buck," closer examination revealed that the options necessary to make the computer a viable tool raised the price upward significantly. Naturally, those companies making "clones" were quick to point that out. The display card, and other absolutely necessary "options" cost extra, as did sufficient memory, mass storage, printer outputs, etc.

Early in the game, IBM noted the limitations of their original PC and offered first an upgrade of disk drives to dual density, double sided—effectively doubling the available storage capacity on each drive. That wasn't enough. The industry was getting storage-hungry and demanded more and more storage, causing both IBM to turn to a hard-disk drive (often called a "Winchester"), which could bring the mass-storage capacity up to 10 megabytes in the same space as a floppy.

As the consumer was becoming memory-hungry, the computer was rapidly becoming power-poor. The PC's power supply was not capable of supplying the demands that the hard disk placed on it. So IBM was forced to offer a hard-disk storage expansion option together with a heftier supply. But that wasn't all bad; the expansion also added extra I/O slots. (The PC's five slots would be fully populated even in a minimal configuration.) The bad part about the expansion unit was that it cost almost $3000.

IBM finally determined what the customer wanted and needed: adequate memory, and more mass storage. Thus, the PC XT was introduced. The letters "XT" were chosen to give the feeling that the computer really had something "extra." (But is it really extra, or is it the minimal configuration that the PC should have been sold in from the start?)

A real computer

The basics "musts" for a personal/business computer are shown in Fig. 1, a block diagram of the motherboard or system board of the IBM PC XT. A listing of the basic specifications of the PC XT is shown in Table 1.

In that PC XT, three of the eight expansion slots are occupied by asynchronous communications, floppy-disk drive and fixed-disk adapter cards. The price shown ($3895) includes those cards, and 256K RAM. The operating system, PC-DOS 2.10 is optional, and sells for $65.00. The price shown in Table 1 does *not* include any graphics or video-output card.

No matter how you might look at it, when you take into account the operating system, display adapter card, and printer port, it will cost you in the neighborhood of $5000 before you have a meaningful computer. That kind of price makes a lot of people wonder just what they're paying for. Is it a premium for the IBM logo, or is it the real value or cost of the computer (known in the trades as MOL or manufacturing overhead and labor). Well, in order to answer that question, let's see what it would cost to put together a basic IBM PC using IBM parts. Then we'll do the same using parts from HiTech.

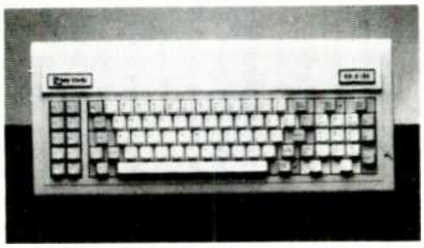


FIG. 2—THE KEY TRONIC keyboard features a more comfortable feel and layout.

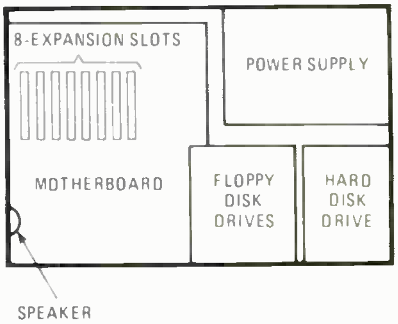


FIG. 3—THE BASIC INTERNAL ARRANGEMENT of the HiTech PC. Note that the 8 slots will accept full-size boards—an advantage over the IBM machine.

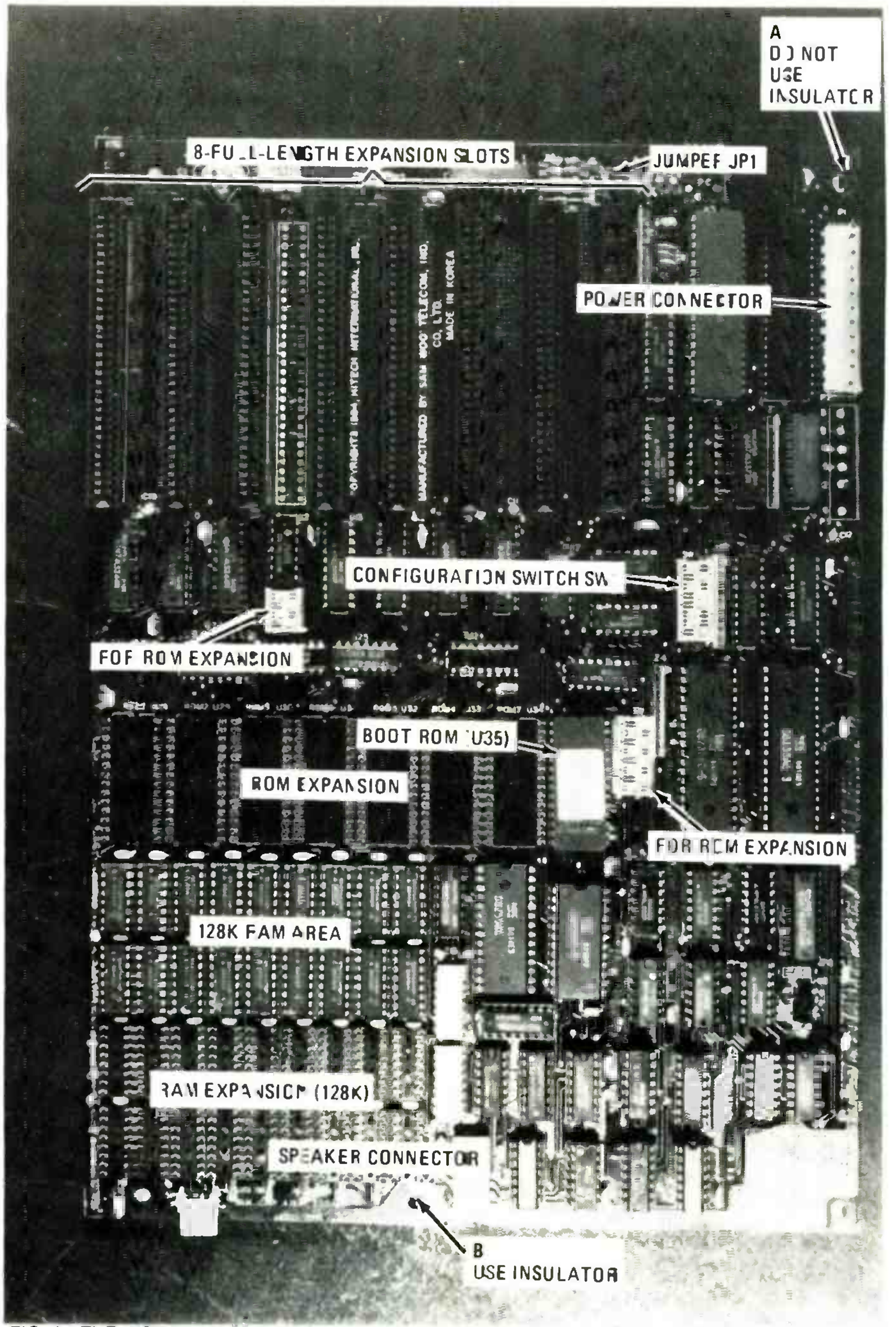


FIG. 4—THE HITECH MOTHERBOARD and some of the features you'll have to be familiar with.

Table 2 shows some pricing data from IBM's Part's Center. (When quoted those prices we were told that "...these prices are firm for today only and may change at any time...") Reduced to its basic building-block level (system board, case, power supply and keyboard assembly) we see that we could put together a PC with 128K RAM but no disk drives for just under $1800. (Note that parts numbers are listed shown in Table 2 with the exception of the Keyboard, which is made up of many separate items—at the manufacturing stage—and will be lumped together with the total cost.)

What would be the cost for the same system using parts from HiTech? Are there any real savings and are there any differences? Table 3 shows the prices for HiTech's basic PC. As you can see, the price is about $1050—a saving of about $700. What do you lose? IBM BASIC, which is contained in ROM in the PC. But disk BASIC is supported.

Do you get anything extra? We should note that the keyboard that's furnished by HiTech is the Key Tronic model *5150*, shown in Fig. 2. It's fully IBM-compatible but features a "corrected" keyboard layout with a feel not unlike the IBM Selectric typewriter.

Now that we've looked at the savings you can hope for with the basic model, let's look at a more fully equipped model. Table 4 lists the specifications for HiTech's version of the XT, which you can compare to Table 1. We should note that two of the eight expansion slots are occupied by a combination printer/floppy-drive controller and the hard-disk controller. In a similar configuration, an IBM PC XT would have two long and one short expansion slots filled. We should also note that the HiTech expansion slots will accommodate eight full-sized adapter boards as opposed to the IBM's capacity for 5 long and 3 short boards. The price shown does not include a video or graphics adapter card. We should also note that the price shown is for a user-assembled system.

As with the IBM, the operating system (PC-DOS 2.10) is optional and has a suggested retail price of $65.00. If the standard IBM PC DOS Version 2.10 is used the system will not support BASICA. If the COMPAQ PC DOS Version 2.10 is used, all disk BASIC functions will be supported.

Building the Computer

Now that we've introduced you to the HiTech PC-compatible, it's time to put it together. Assembling your system really is easy and anyone can do it. HiTech seems to have set a standard for simplicity of assembly. The only tool you'll need is a common 1/4-inch flat-bladed screwdriver. And you'll need only about one hour. So we'll assume that if you can turn a screw, you will build your own PC-compatible computer.

Before we go any further, we should point out that a bare board is available from HiTech for $95. So if you really want to assemble your computer piece-by-piece, you can. Whether you can really save any money depends on how well you can shop for bargains on IC's, connectors, etc. Be advised, however, that because HiTech cannot control how you put your board together, they cannot issue any warranty for a bare board.

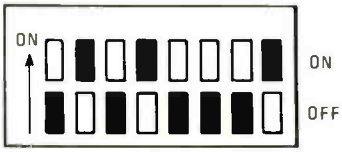


FIG. 5—THE PROPER SETTING of the configuration switch for our system.

So, assuming that you'll start with a ready-assembled mother board, let's run down the features and components your computer will have:

- Systemboard with 128K RAM
- Single 360KB floppy disk drive
- 10 megabyte hard-disk drive
- 130-watt power supply
- Key Tronic 5150 keyboard
- Parallel printer port
- Applicable controller cards
- Color graphics/monochrome display adapter

continued on page 136

Now that we've introduced you to the HiTech PC-compatible computer, let's see how it's put together.

ELLIOTT S. KANTER

Part 2 WHEN WE LEFT OFF last time, we were just getting ready to configure the motherboard. The first step is to set the configuration switch SW1, which is a DIP switch that is made up of eight separate switches that we'll call SW1-1–SW1-8.

As we showed you last month, for our configuration the switches should be set as follows:

- SW1-1: OFF.
- SW1-2: ON.
- SW1-3: OFF.
- SW1-4: ON.
- SW1-5: OFF.
- SW1-6: OFF.
- SW1-7: OFF.
- SW1-8: ON.

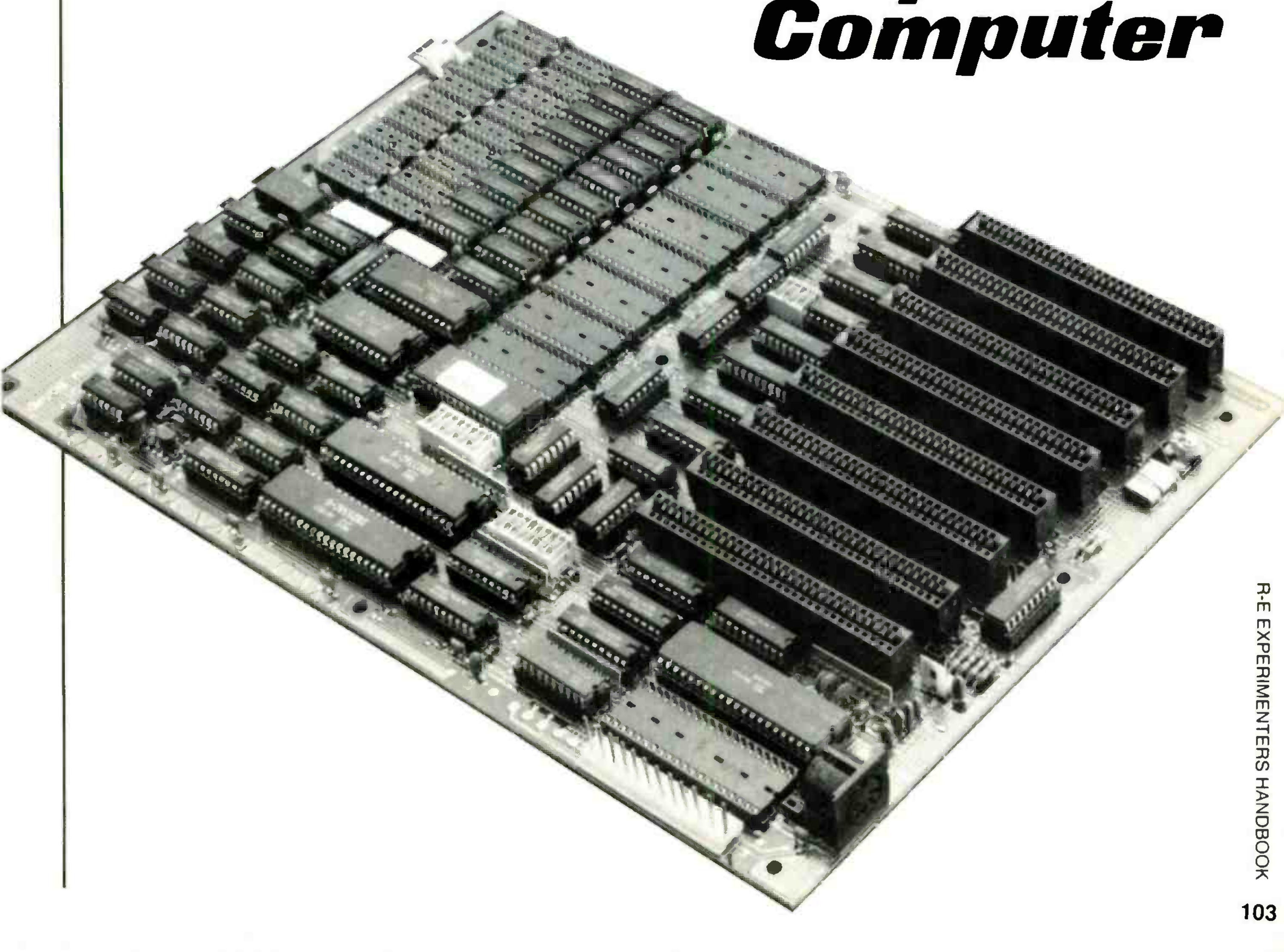
Switch SW1-1 is always off for normal operation, while SW1-2 is on unless an 8087 co-processor is being used.

Switches SW1-3 and SW1-4 are set depending on how much memory is installed. For 128K, they should be set off and on respectively. For 192K, they should be set on and off, respectively. For 256K, they should both be off.

Switches SW1-5 and SW1-6 are set depending on the display adapter used. They should both be on if no display adapter is used. If a color/graphics adapter (with 40 × 20 resolution) is used, SW1-5 should be off, but SW1-6 on. For a resolution of 80 × 25, those settings should be reversed. If both adapters are used, or if a monochrome adapter is used, both SW1-5 and SW1-6 should be off.

Switches SW1-7 and SW1-8 are set de-

PC Compatible Computer



pending on how many floppy-disk drives are installed. For 1 drive, both should be on. For 2 drives, SW1-7 should be off, but SW1-8 should be on. For 3 drives, SW1-7 should be on, but SW1-8 should be off. For 4 drives, both should be off.

Two other DIP switches are located on the motherboard. Those switches are not numbered but their locations are labeled "FOR RAM EXPANSION" in Fig. 4. (For your convenience, Fig. 4, which appeared last time, will be repeated here.) Unless you have the necessary expertise to implement alternative ROM/EPROM's, don't disturb the settings.

Now it's time to insert the BIOS ROM in position U35. Be sure to observe the orientation of the notch or dot indicating pin 1.

Now that you have completed the switching configuration process, you're almost ready to install the board in the case. Before you do, locate the jumper block JP1. (See Fig 4.) If you are using the HiTech Power Supply, ensure that a jumper is in place from pins 2 to 3. That jumper enables the on-board power-on reset. If you are using the IBM power supply, install the jumper from pins 1 to 2.

The system board is now ready to be installed. It will be secured by a locking-type, plastic stand-offs and two, 6-32 × 1/4-inch screws. As noted in Fig. 4, one screw will be mounted with an insulating washer separating it from the component side of the board. With the case positioned as shown in Fig. 3 (see the July 1985 issue of **Radio-Electronics**), slide the system board in from the left and line up the plastic locking-type stand offs with the holes in the board. Those stand-offs will slide in their mounts making this task easier. When you have lined the board up and the stand-offs protrude through the holes, press down to lock the board into place.

Refer again to Fig. 4 and install the screw without the insulating washer where shown (point A). In a similar manner install the screw with the insulating washer where shown (point B). Take the two-wire cable coming from the speaker and plug it into the on-board connector as also shown in Fig. 4. That completes the installation of the system board.

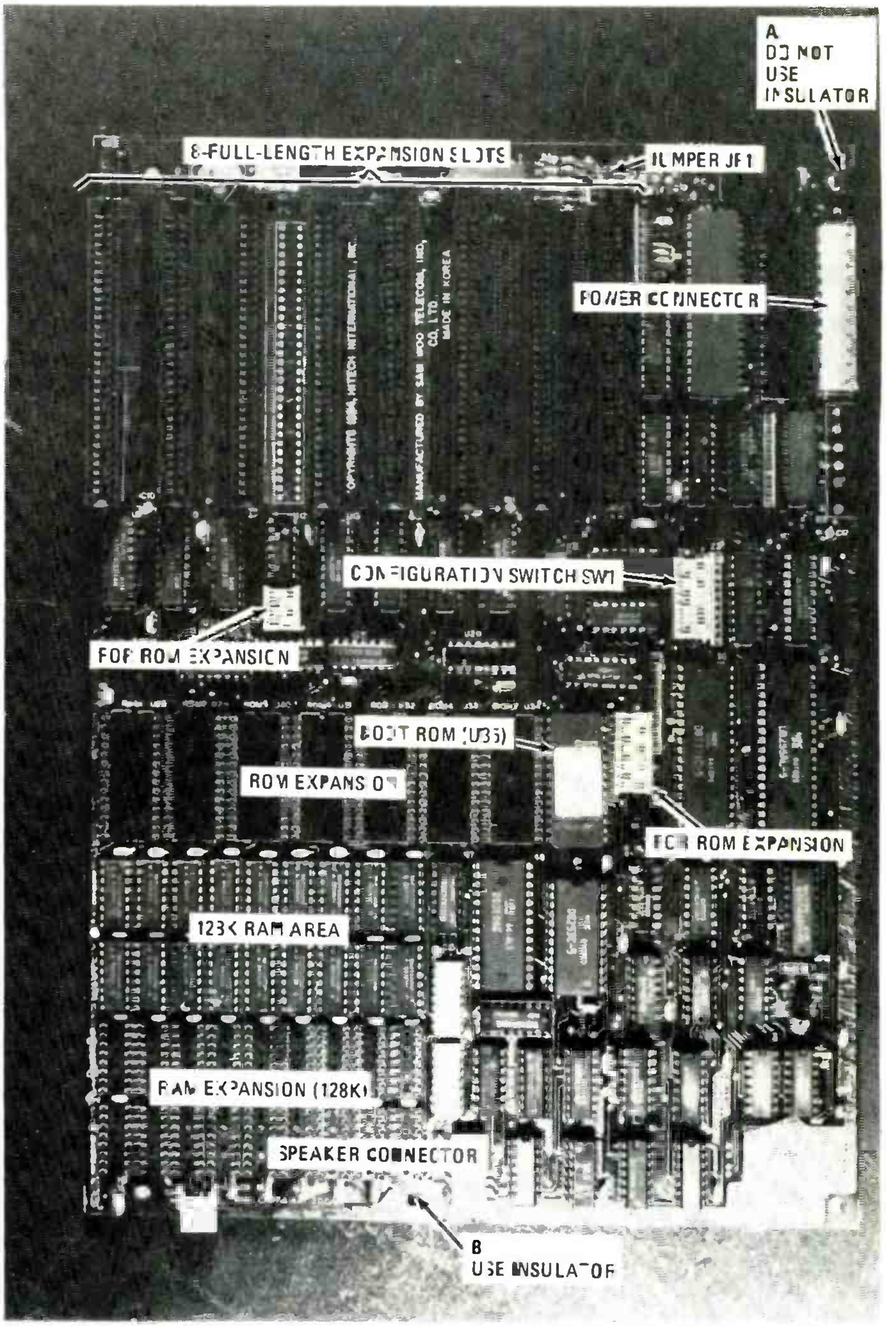


FIG. 4—THE HITECH MOTHERBOARD and some of the features you'll have to be familiar with.

Configuring the disk drive

If you have not done so already, carefully unpack the floppy-disk drive. Position the drive as shown in Fig. 6 and locate the power connector and the data-cable connector. Using a screwdriver, gently pry out resistor pack RA1 and discard it; it is not required for use with the HiTech PC. Next, move the jumpers; they should be at the HS and DS1 positions. That's all there is to configuring your floppy-disk drive. If you have purchased a second disk drive, configure it in exactly the same manner.

You are now ready to install the floppy-disk drive in the case. Pop out the lower of the two plastic drive faceplates and carefully insert the disk drive, component-side down, through the front of the case. Secure the disk drive using two 6-32 × 1/4-inch screws in the slots (bracket) and tapped holes (disk drive) ensuring that the drive front is lined up with the front of the panel. The direction-indicating arrow on the front of the disk drive should be pointing up. That's all there is to installing the drive. If you have purchased a second disk drive, install it in a similar manner.

Installing the hard-disk drive

Your hard-disk drive, despite its name, is fragile. You should take whatever precautions are necessary to prevent it from jarring or dropping. (Damage can occur if it's dropped from heights as little as two inches!) Unpack the disk drive and remove the plastic front panel cover from your computer.

Refer to Fig. 7 and gently slide the drive into the right-hand side opening (as viewed from the front). Using the supplied mounting screws, secure the drive to the bracket as shown in the drawing. That completes the installation of the drive proper. The next step is to install the controller card.

Hard-disk controller

If you have not done so already, unpack the hard-disk controller card and position it in front of you as shown in Fig. 8. Locate the DIP configuration switch

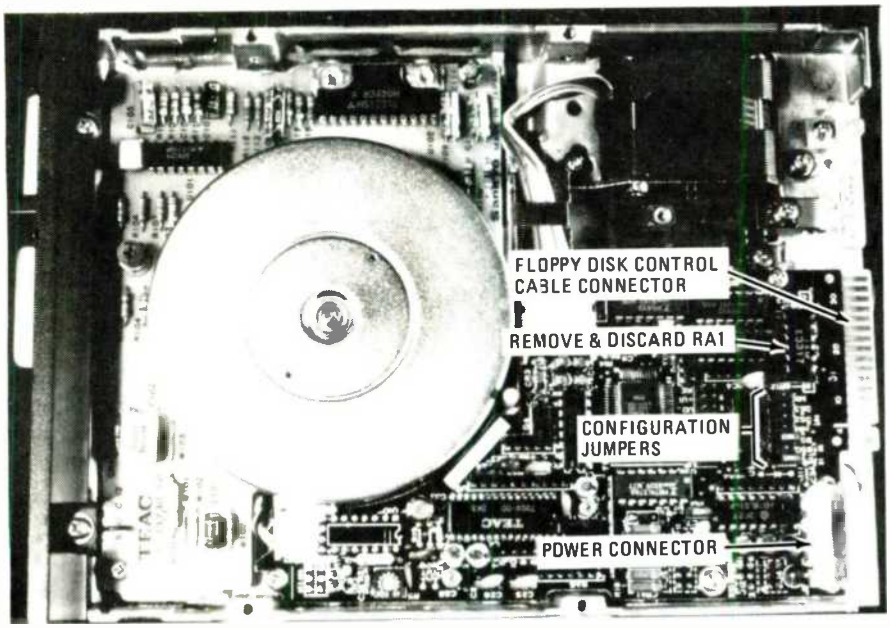


FIG. 6—THE FLOPPY-DISK DRIVE. The resistor network RA1 can be discarded. See the text for the proper jumper configuration.

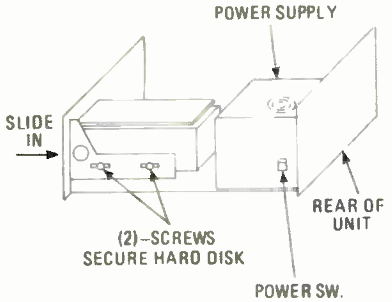


FIG. 7—MOUNTING THE HARD DISK and power supply is straightforward.

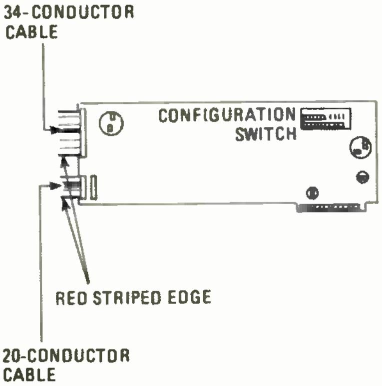


FIG. 8—THE HARD-DISK CONTROLLER CARD. The first four positions of the configuration switch should be set to off, and the last four should be set on.

SW1. (Note that this SW1 is *not* the same SW1 that we set on the system board.) The controller supplied with your computer is capable of accepting hard disks ranging in capacity from 10MB to 30MB. SW1 configures the card to the drive installed. In our case, we will be installing and configuring this card for a 10MB disk, so set SW1-1 through SW1-4 off and SW1-5 through SW1-8 on. That's all you have to do to configure the controller card. Don't change any jumpers on the card. You're now ready to install it, using Fig. 9 as a guide.

Using the supplied cables, plug the 20-pin and 34-pin cables into the card as shown with the red striped end of the cables pointing down toward the card-edge connector. Insert the card into a vacant slot near the hard-disk drive and route the cables as shown toward the hard disk. You will have to remove one of the back slot covers to install the card; save the screw and use it to secure the card with the cable end pointing towards the computer's front panel. Connect the remaining ends of the cables to the hard-disk drive. They are keyed and can only be inserted in the proper manner. Your hard-disk drive and controller card are now installed. We will format the disk shortly.

Installing the power supply

Position the power supply so that the power switch is located to the right rear (as viewed from the front) and protrudes from the rear right hand side of the case. (Refer to Figs. 7 and 10.) Turn the case around and line up the four mounting holes with their corresponding holes in the rear panel. Using four 6-32 × 1-inch round-headed screws, secure the power supply to the rear of the case. Locate the two cable assemblies and connect them to the motherboard as shown. In a similar manner, connect one of the two, 4-line cable assemblies to the rear of the hard disk drive. The assembly's connector is keyed and can only be inserted the correct way.

The remaining 4-line cable assembly will be connected in a similar manner to the floppy disk drive. If you are using two drives, use the y-adapter and carefully match the color codes of the wires and crimp the adapter in place.

The adapter cards

Now it's time to install a color-graphics/monochrome display card and a flop-

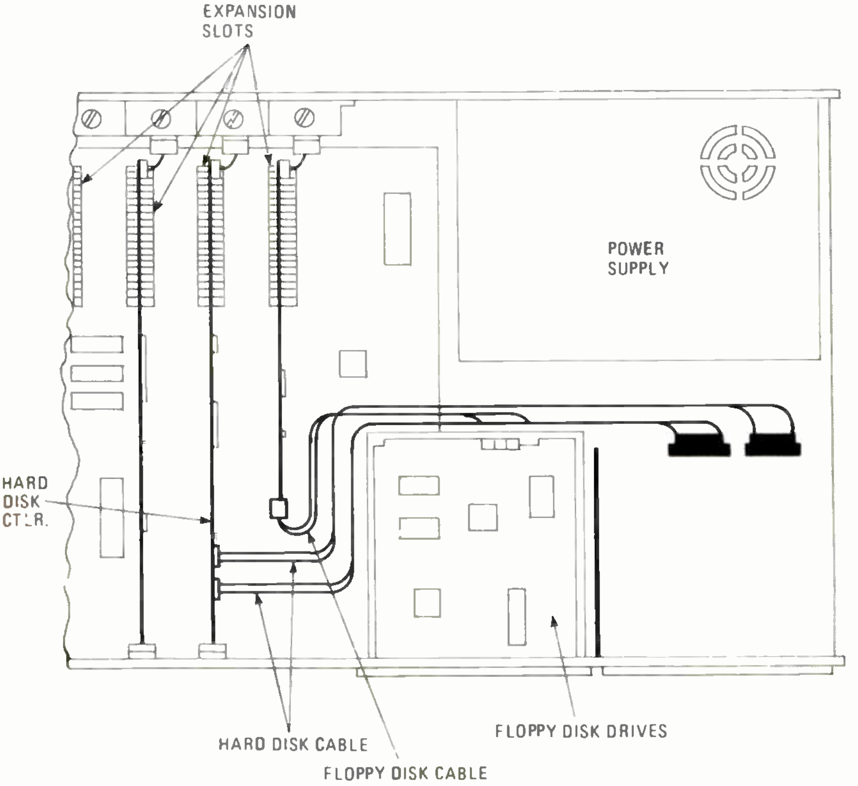


FIG. 9—ROUTING THE RIBBON CABLES for the disk drives is easy if you follow the layout shown.

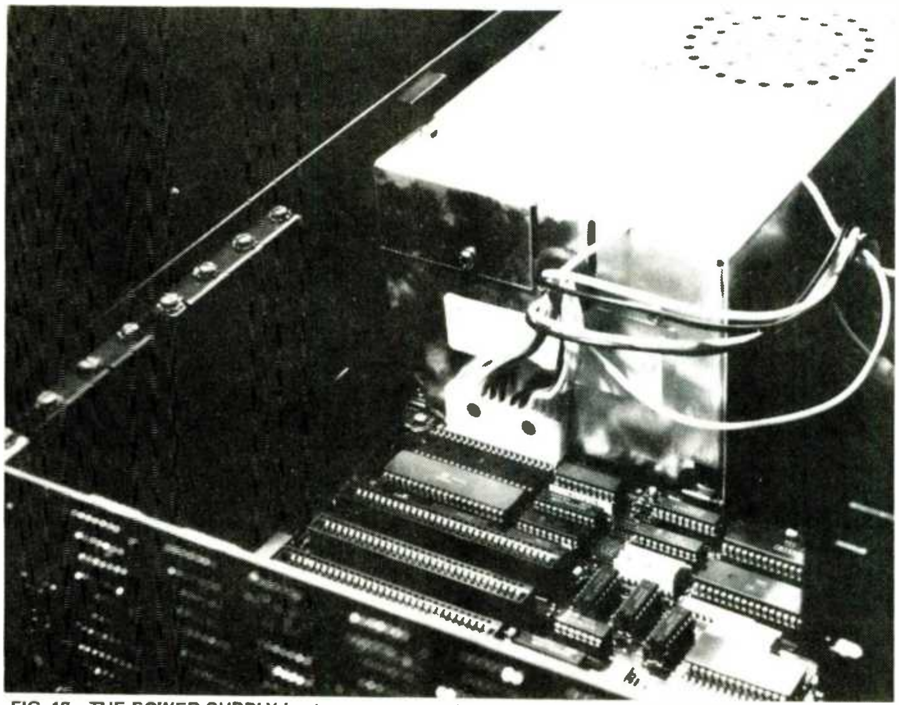


FIG. 10—THE POWER SUPPLY is shown connected to the motherboard. Note that the cables for the floppy- and hard-disk drives are not shown.

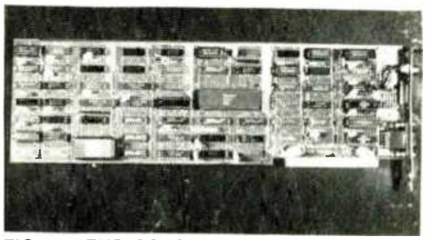


FIG. 11—THE COLOR graphics/monochrome adapter is fully compatible with the IBM system.

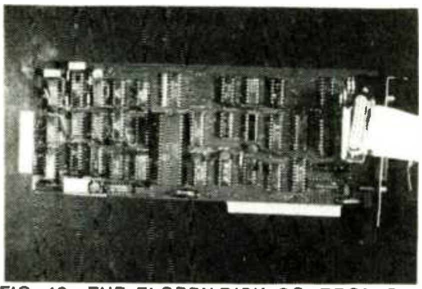


FIG. 12—THE FLOPPY-DISK CONTROLLER adapter shown here also comes equipped with a parallel printer port.

py-disk controller/parallel printer card. Each of those cards is packaged separately with necessary cables and instructions as to use. The color-graphics/monochrome display card shown in Fig. 11 should be installed in the first (left-most) expansion slot with the two connectors—one for RGB color, the other for composite video—visible from the rear. Remove the screw holding the rear panel cover corresponding to the first slot (right as viewed from the front). Discard the panel cover but retain the screw; it will be used later to secure the adapter card. Position the card with the connectors to the rear and press down firmly. Secure the rear panel bracket

The last adapter card we'll install is the floppy-disk controller card with a parallel printer port. Remove the third and eighth rear panel covers and save the screws. The left-most opening will be used for the DB25 parallel printer port connector. The remaining (third) opening will be filled with the expansion-drive connector.

Refer to Fig. 12, the controller/printer adapter. The only required configuration would be to change the position of the jumper located nearest the card edge fingers. The purpose and possibilities of that configuration change are more than adequately covered in the documentation that comes with the card and will not be repeated here.

Position the card so that the gold fingers on the long edge of the board are directly above the connector and ensure that the plate attached to the board lines up with the now open rear slot. Firmly press the board down into the connector and replace the screw removed previously to hold the board in place.

Take the cable supplied and place it between the floppy-disk drive(s) and the controller card with the red edge of the cable pointed to the top of the computer. If you are using only one drive, locate the connector at the fold of the cable and press the connector onto the bottom disk drive. The red line should be visible toward the left as seen from the front of the computer (on the disk drive). If you are using a second floppy drive, position the connector at the split end of the cable in a similar manner and press this connector onto the top disk drive. The remaining connector located at the long end of the cable should be connected to the card adapter with the red edge line pointing to the top or up. Route this cable as shown previously in Figure 9. That completes the installation of the floppy disk controller. To mount the DB25 parallel printer port, fasten this connector to the (supplied) bracket with the hardware supplied. Position that connector and bracket in the last opening and secure it with the remaining screw removed previously.

We're now ready to close up the case and try things out! Slip the case cover on from the front and secure with the four 6-32 × ¼-inch black flat head screws. Plug the connector from the keyboard into the socket located on the rear of the cabinet. Figure 13 shows the completed system which is also available ready to use under the name SAM 2001.

The "smoke test"

Now hook up your monitor, plug everything in, slip your operating-system disk into drive A (the top drive), and turn the computer on. The screen display will show the self-test in progress. When the self-test is complete, it will instruct you to insert your system diskette in the drive and to press any key.

At the system prompt, you might wish to enter DIR followed by RETURN to view the contents of your system disk. For detailed information on your system disk and the various uses of the utilities it contains, consult the literature that comes with the diskette, or any of the many fine books available on the MS-DOS operating system.

Formatting the hard disk

Now that everything seems to be working right, it's time to format the hard disk. Leave your DOS disk in drive A and enter "FDISK" followed by a return. A menu will present you with a number of options. Select Option 1 .

In response to the prompt asking if you want to use the entire fixed disk for DOS, answer NO .

In response to the prompt asking for partition size, enter 303.

In response to the prompt asking for the starting cylinder number, enter 0.

Hit the ESC (Escape) key to return you to the FDISK options. In order to make the partition active so that the system will load the DOS on power-up, select option 2.

View the partition data and double check it. You will be prompted to enter the number of the partition you want to make active. Select 1. Then hit the ESC key to return to the FDISK options. Use the ESC key again to return to DOS.

Reboot your system by hitting CTRL ALT DEL (the control, alternate and delete keys) simultaneously.

Next we'll use the DOS command FORMAT to initialize the hard disk's directory. First type "FORMAT C:/S."

ADD-ON BOARD SUPPLIERS

ABM Computer Systems
3 Whatney
Irvine, CA 92714
714-859-6531

Apstek Inc.
2636 Walnut Hill Lane Suite 335
Dallas TX 75229
214-357-5288

AST Research, Inc.
2121 Alton Ave.
Irvine, CA 92714
714-863-1333

Byad, Inc.
95 W. Algonquin Road
Arlington Heights, IL 60005
312-228-3400

Chrislin Industries, Inc.
31352 Via Colina Suite 1
Westlake Village, CA 91362
213-991-2254

IDE Associates, Inc.
7 Oak Park Drive
Bedford, MA 01730
800-257-5027

MA Systems
2015 O'Tolle Ave.
San Jose, CA 95131
408-943-0596

Maynard Electronics
430 E. Semoran Blvd.
Casselberry, FL 32707
305-331-6402

Microlog, Inc
222 Route 59
Suffern, NY 10901
901-368-0353

Orchard Technology
47790 Westinghouse Drive
Fremount, CA 94539
415-490-8586

Personal Computer Products, Inc.
11590 W. Bernardo Court
San Diego, CA 92127
619-485-8411

Persyst
17862 Fitch
Irvine, CA 92714
714-660-1010

Profit Systems, Inc.
30200 Telegraph Rd. Suite 132
Birmingham, MI 48010
313-647-5010

Quadram
4355 International Blvd.
Norcross, GA 30093
404-923-6666

Tecmar
6225 Cochran Rd.
Bolon, OH 44139-3377
216-349-0600

ORDERING INFORMATION

The following are available from HiTech International, Department R-E, 1180 Miraloma Way Suite M, Sunnyvale, CA 94086.

Part No.	Description	Price
RE-PCB W/IC	Motherboard with 128K RAM	$525.00
RE-PS-130	130-watt power supply	175.00
RE-ROM	BIOS ROM	35.00
RE-CASE	Case (complete)	150.00
RE-5150	enhanced keyboard	150.00
RE-MON/DIS	RGB video card	175.00
RE-DISK DR.	Teac 360K disk drive	125.00
RE-CTRL-A	Disk controller/parallel port	175.00
RE-HARD DISK	10 megabyte drive with controller	650.00
RE-YAD	Y Adapter (to attach two drives)	5.00
		Total*: 2165.00

*Note that due to last-minute price changes by both IBM and HiTech, the price difference between their two compatible computers does not live up to the $2000 claimed on last month's cover.

FIG. 13—THE COMPLETE HITECH COMPUTER is avai able fully assembled as the *Sam 2001*.

You'll be prompted to hit any key to begin formatting drive C. When you do, don't be surprised at the amount of time required to format the hard disk. You will be able to tell that the hard disk is working by the drive indicator light being illuminated. When formatting is complete, a status report will be displayed telling you the total disk space, the space marked as defective, and the space currently allocated to files. Note that the amount of space marked as defective must be ZERO. If any bad bytes are found, you should contact HiTech International.

As we have seen, the DOS command FORMAT is required to setup the hard disk, it also initializes it. Initialization could be disastrous if used at the wrong time. The same command is also used to format the floppy disks, so if you used it in error, the hard disk could in fact be erased. To prevent that from happening, change the name FORMAT.COM to FMT.COM. To do so type "RENAME FORMAT.COM FMT.COM."

Next create a batch file to format floppy diskettes. To do so type: "COPY CON: FORMAT.BAT FMT A%1." Then hit the F6 key. That program will enable you to format a diskette or to format and place DOS on your diskette. To only format the diskette type FORMAT; to both format and add DOS, type FORMAT/S.

That completes the formatting and configuration of your hard disk. You are now ready to enjoy your system.

Add-ons, etc.

One of the advantages of building your own system is the ability to tailor accessories to your needs. There are a lot of companies making accessories for the IBM PC/XT and anything that fits the IBM, will work in your HiTech computer. To offer you some assistance, we are including a list of suppliers of accessories that will permit memory expansion, additional ports (serial, parallel, game, etc.) and the ability to configure additional memory as a RAM disk. **R-E**

BUILD THIS

Bar-Graph Voltmeter

for your CAR

Your car's ammeter can't warn you about impending battery failure. But this bargraph voltmeter will help you keep tabs on your car's charging system!

STEVE PENCE

HAVE YOU EVER BEEN STRANDED IN A parking lot because of a dead battery? Nearly all of us have at one time or another—usually at the most inconvenient time. But that situation could be easily avoided if you knew your battery's condition.

Adding a voltmeter to your dashboard instruments is the best way to track your battery's performance. We'll show you how to build a voltmeter that's a bit different from the ones you are accustomed to seeing. Instead of a traditional mechanical meter movement, this one uses a sleek-looking, easy-to-read bargraph display. The display uses ten LED's (*Light Emitting Diodes*) to display a voltage range from 10.5 to 15 volts. Each LED represents a 0.5-volt step in voltage.

The voltmeter is designed around National Semiconductor's LM3914 dot/bar display driver. Using that IC keeps the rest of the circuit simple: only 15 passive components plus the 10 display LED's are required.

The voltmeter circuit

The schematic of the voltmeter is shown in Fig. 1. The heart of the circuit is IC1, the LM-3914 dot bar display driver. That IC contains nearly everything needed to construct a surprisingly accurate voltmeter.

As you can see from the simplified representation of the driver's internal circuitry shown in the schematic, the device contains a precision voltage reference source that is very stable over a wide range of supply voltages and temperatures. It also has a precision voltage-divider chain made up of ten 1K resistors.

When the voltage reference is properly connected across the divider chain, 10 very accurate voltages are set up at the junctions of each of the 1K resistors. Each of these reference voltages are fed to the input of a separate comparator, which compares the reference voltage with the voltage presented to the input at pin 5.

If the input voltage is greater than the reference voltage, the comparator's output will go low, turning on its respective LED. As the input voltage goes higher, successively higher LED's turn on. The voltage that each LED represents is determined by the total voltage applied to the divider chain. If one volt is applied then each step will equal .1 volt.

You will note that the input voltage applied to pin 5 is first divided in half by R1 and R2. That's because the 3914 cannot measure a voltage that is equal to its supply voltage. We use the voltage divider to cut it in half to provide plenty of headroom. This means that when the battery voltage changes by .5 volt the input to the driver sees only a .25-volt change.

In order for the driver to measure in .25-volt steps we must apply 2.5 volts to the internal divider chain. That is accomplished by setting trimmer potentiometer R5 to the correct value. The internal voltage reference is set up to provide a constant current down through R5 (which is in parallel with the precision divider) and through R6. The voltage dropped across R5 is therefore also seen across the precision divider.

Resistor R6 is needed because we must begin our measurement at 10.5 volts instead of ground. That resistor essentially extends the bottom of the internal divider. The first comparator therefore turns on when the input signal is .25 volt above the voltage seen at the top of R6. If the constant current from the reference source is set to provide a 5.0-volt drop across R6, then the first comparator will turn on when the input voltage is equal to 5.25 volts (which corresponds to a battery voltage of 10.5 volts that is divided in half).

Trimmer potentiometer R5 is next adjusted to so that 7.5 volts is applied to the top side of the divider. You now have 2.5 volts across the divider for the required .25 volt per step. Since the current through R5 and R6 is constant, the voltage dropped across R6 will be constant, even if the value of R5 is changed.

Resistor R7 and diodes D2 through D5 clamp the voltage applied to the LED's to about 3 volts. This limits the power that the driver IC must handle and improves measurement linearity.

The electrical systems of most automobiles are extremely noisy, often producing narrow spikes as much as 200 volts in amplitude. Spikes of that magnitude

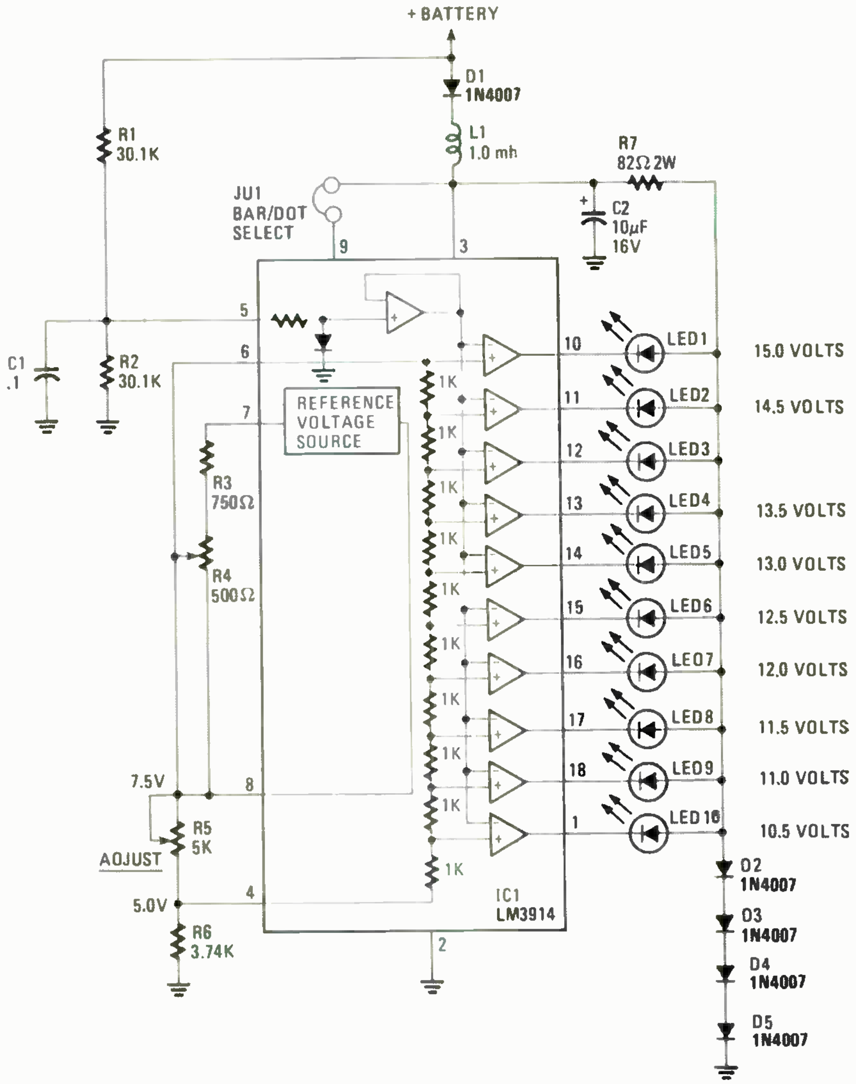


FIG. 1—THE BARGRAPH VOLTMETER SCHEMATIC shows that the circuit is not complex. To make the meter easy to read at a glance, you might consider installing yellow, green and red LED's to represent different voltage ranges.

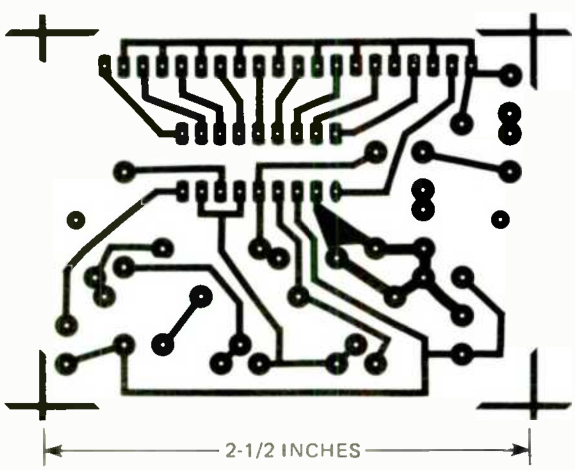


FIG. 2—THE FOIL PATTERN for the bargraph voltmeter is shown full size. The circuit layout is not critical, so you may prefer to use point-to-point wiring. But a PC board will certainly keep things neater.

can easily ruin a project of this nature if precautions are not taken. A lowpass filter made up of L1 and C2 guards against voltage spikes. Diode D1 is used to protect against reverse voltage in case the voltmeter is hooked up backward. Although those three components are not required for the voltmeter to operate, you should install them: They do increase long term reliability.

Building the voltmeter

The bargraph voltmeter is easy to build. It's made up of a printed-circuit board, one integrated circuit, and a few discreet components. A PC board is not essential, but it certainly is a convenience. A foil pattern for a board is shown in Fig. 2. You can, however, build the meter using pre-punched circuit board and point-to-point wiring techniques. The layout of the circuit is not critical. The parts are available from a large number of electronics distributors or from the source listed in the parts list.

Once you have all the parts together, you can begin assembly by installing the components by following the parts-placement guide of Fig. 3. Remember that the diodes, the LED's, and capacitor C2 are polarized and must be installed in the correct direction.

When installing the LED's be sure they are all placed the same height from the PC board (approximately .150 inches). That's most easily done by having someone hold the board for you while you solder them into place. Have him hold the board foil side up, with the LED's installed over a flat surface. That will force the faces of all the LED's to be at the same height from the board. After they are all soldered in, bend them over so they are parallel to the surface of the board (see Fig. 4).

If you have access to different-colored LED's, you might consider installing them to signal different voltages. For example, yellow could represent anything under 12 volts, green could indicate inputs between 12 and 14 volts, and red could be used to indicate that your battery is overcharging.

Don't forget to install the jumper wire, J1, on the printed circuit board. That programs the LM3914 to display in the bar-mode. If, on the other hand, you prefer the dot mode (in which only one LED at a time comes on) simply leave the jumper out.

Calibrating the meter

Calibration is easy to do—but it does require the use of an accurate voltmeter as a reference. The calibrating meter should be able to read to within at least .1 volt on a 10-volt range.

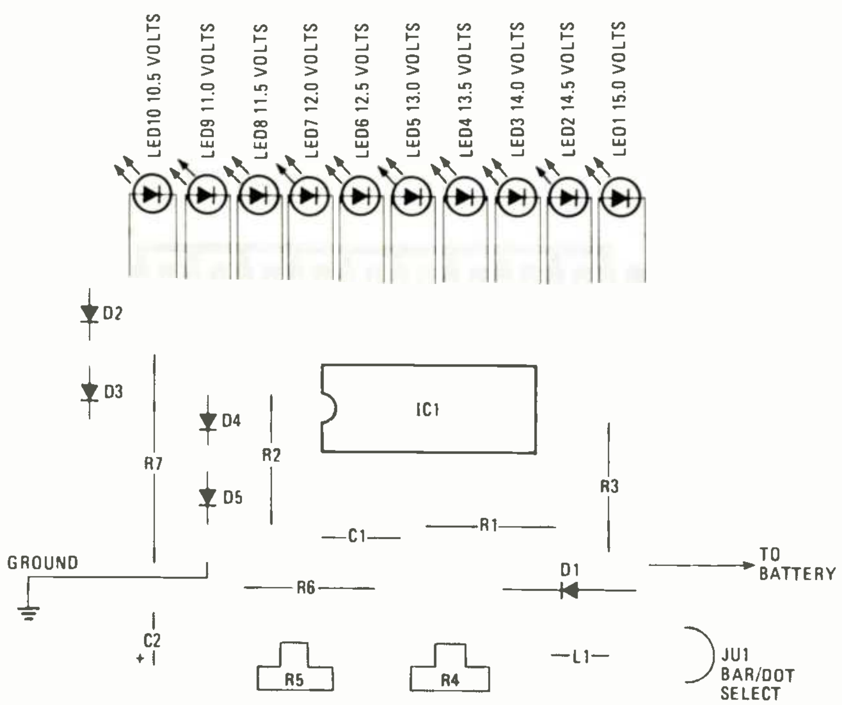


FIG. 3—PARTS PLACEMENT DIAGRAM. Note that for the unit to read from left to right, it must be installed foil-side up.

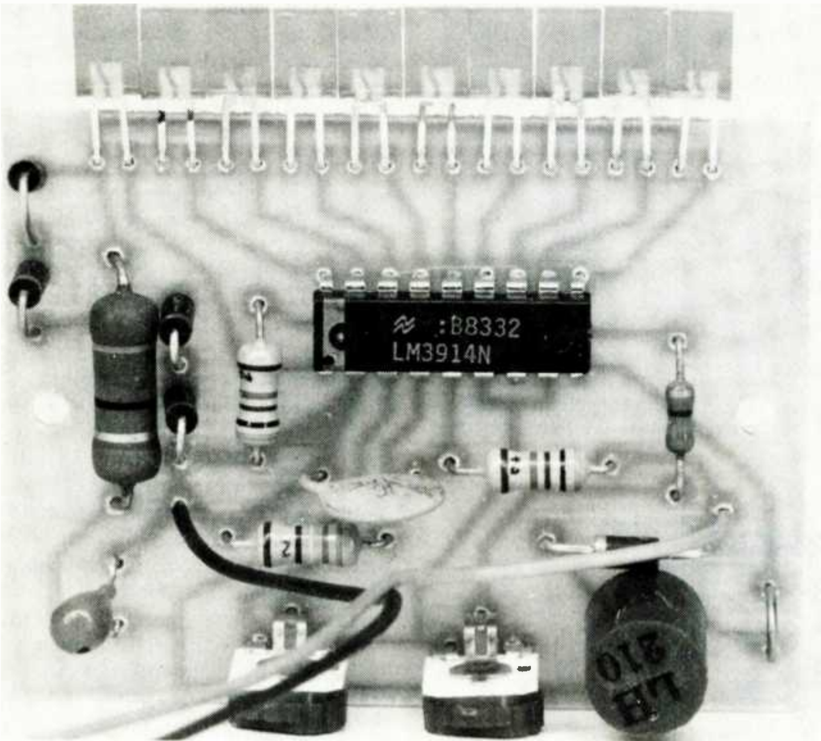


FIG. 4—THE ASSEMBLED VOLTMETER BOARD. When you install the LED's, make sure that you keep them all the same height, and bend them evenly.

Preset variable resistors R4 and R5 to the center of their range. Connect the meter to a source between 12 volts and 15 volts. With your calibrating voltmeter, measure the voltage from pin 4 of the IC to ground (across resistor R6). Adjust R4 for exactly 5.0 volts at this point.

Next measure the voltage from pin 8 of the IC to ground (across R5 and R6). Adjust R5 for exactly 7.5 volts. The two adjustments should not interact, but recheck the voltage at pin 4 just to be sure.

Installing the voltmeter

Mechanically, there is only one thing you have to keep in mind when installing the voltmeter: In order for the display to read from left to right, the PC board must be mounted with the foil side up.

Many cars come equipped with an ammeter to indicate charging is taking place. Although this tells you that the alternator is charging, it does not tell whether or not the battery is accepting the charge. A voltmeter on the other hand lets you know immediately what is happening in the charging system. It can give you advanced warning that your battery is on the way out.

If your battery is fully charged, the engine is not running, and no accessories are on, you should measure 12 to 12.5 volts. If the battery is placed under load by turning on the headlights the voltage should drop only a half a volt or so. After starting the engine, the alternator will quickly bring the battery voltage up to 13 or 14 volts if the system is charging properly.

If the alternator voltage were to rise more that 2 volts above the battery voltage, it would indicate overcharging. One possible reason could be a bad voltage regulator ground. Overcharging will cause excessive boiling of the electrolyte and warping of the plates. That can lead to internal shorts.

If the battery isn't holding a charge properly, it is easily detected by checking the voltage just before starting the engine. If the voltage has dropped to 11 volts or less over night, you may soon be stuck in a parking lot somewhere.

One of the real advantages to the voltmeter is that you become accustomed to the normal pattern of voltage fluctuations. When a problem rears its head, the pattern will change and you then have an early warning of impending doom. **R-E**

PARTS LIST

Resistors
R1, R2—30,100 ohms, 1/4 watt, 1%
R3—750 ohms 1/4 watt, 5%
R4—500 ohms trimmer potentiometer
R5—5000 ohms, trimmer potentiometer
R6—3740 ohms, 1/4 watt, 1%
R7—82 ohms, 2 watts

Capacitors
C1—0.1 µF, ceramic disc
C2—10 µF, 16 volts, tantalum

Semiconductors
IC1—LM3914 bar/dot display driver
D1–D5—1N4001
LED1–LED10—rectangular red LED
L1—1.0 µH choke

The following are available from Elephant Electronics Inc., P.O. Box 41770-P, Phoenix, AZ., 85000: Printed circuit board only, (BVM-1) $5.95; PC board with all board-mounted parts, (BVM-2) $19.95; Kit of all parts including case, (BVM-4) $24.95. Arizona residents add 6% sales tax. Canadian orders please remit in U.S. funds. Allow 4 to 6 weeks for delivery.

Versatile Bench Power Supply

VAUGHN D. MARTIN

No electronics workbench is complete without a variable power supply. If you're still missing that essential tool, here's a versatile six-output supply you'll want to build.

A VARIABLE POWER SUPPLY IS AN ESSENtial part of any electronics workbench. If your workbench is lacking one, then this supply is for you! It's inexpensive, easy-to-build, and it's more than just a power supply: It includes two variable, precision voltage-reference outputs too!

The power supply provides three pairs of complementary voltage sources. Each output has built-in current limiting, and all share a common ground. While the supply is designed for low- to medium-current applications, we'll show you how to increase the current capability of the non-precision sources to 2 amps.

The first pair of voltage sources, $+V_S$ and $-V_S$, are independently adjustable. Each has a 15-volt range of adjustment and can supply a current of 100 ma.

The second pair, $+V_T$ and $-V_T$, is dual-tracking: The outputs, which are adjusted using a single control, are equal in magnitude and opposite in polarity. The adjustment range of the dual-tracking outputs is the same as for the independent supplies. The tracking sources can also supply 100 ma of current.

The third pair of outputs, $+V_P$ and $-V_P$, is a set of precision voltage sources, one positive and one negative with respect to ground. The output of each is set by a 10-turn potentiometer and turns-counting dial. Those supplies have a somewhat wider voltage range (25 volts each), but have very low current output (4 mA). They are intended, once calibrated, to be used as secondary calibration standards, not to supply operating current to working circuitry.

One of the special features of this power supply is that each pair of outputs is completely independent of the others, so you need only build the output pairs that you need. For example, if you don't need the precision source, simply omit all components associated with it. (Even if you omit one section, we recommend using the printed-circuit artwork provided; it will make it easy to add the section later.)

Circuit operation

As you can see from Fig. 1, the power supply is made up of four main sections: The rectifier circuit is shown at the upper left of the diagram, the precision sources at the upper right, the dual-tracking supply at the lower left, and the independent supplies at the lower right.

The rectifier circuit

The rectifier circuit supplies half-wave rectified DC to each section of the power supply. Note that the polarity of the diodes and capacitors for the positive supplies is opposite that of those for the negative supplies. The non-precision supplies are powered by the ±20-volt rectifier outputs, while the precision sources get their raw power from the ±40-volt rectifier outputs.

The independent supplies

Zener diode D5 provides a 6.8-volt reference to the non-inverting input of op-amp IC1. The inverting input will also be at a potential of 6.8 volts due to normal op-amp feedback. The voltage developed by IC1 is dropped across 10K potentiometer R6, the front-panel +SUPPLY control that's used to adjust the $+V_S$ output voltage. The output of R6, which may vary from 0.0 to 6.8 volts, is applied to the non-inverting input of op-amp IC2. The gain of the op-amp may be calculated using the following equation:

$$E_{OUT} = E_{IN}(R10 + R11 + R12)/R12$$

With trimmer potentiometer R11 set at its midpoint, about 2.5K, the factor in

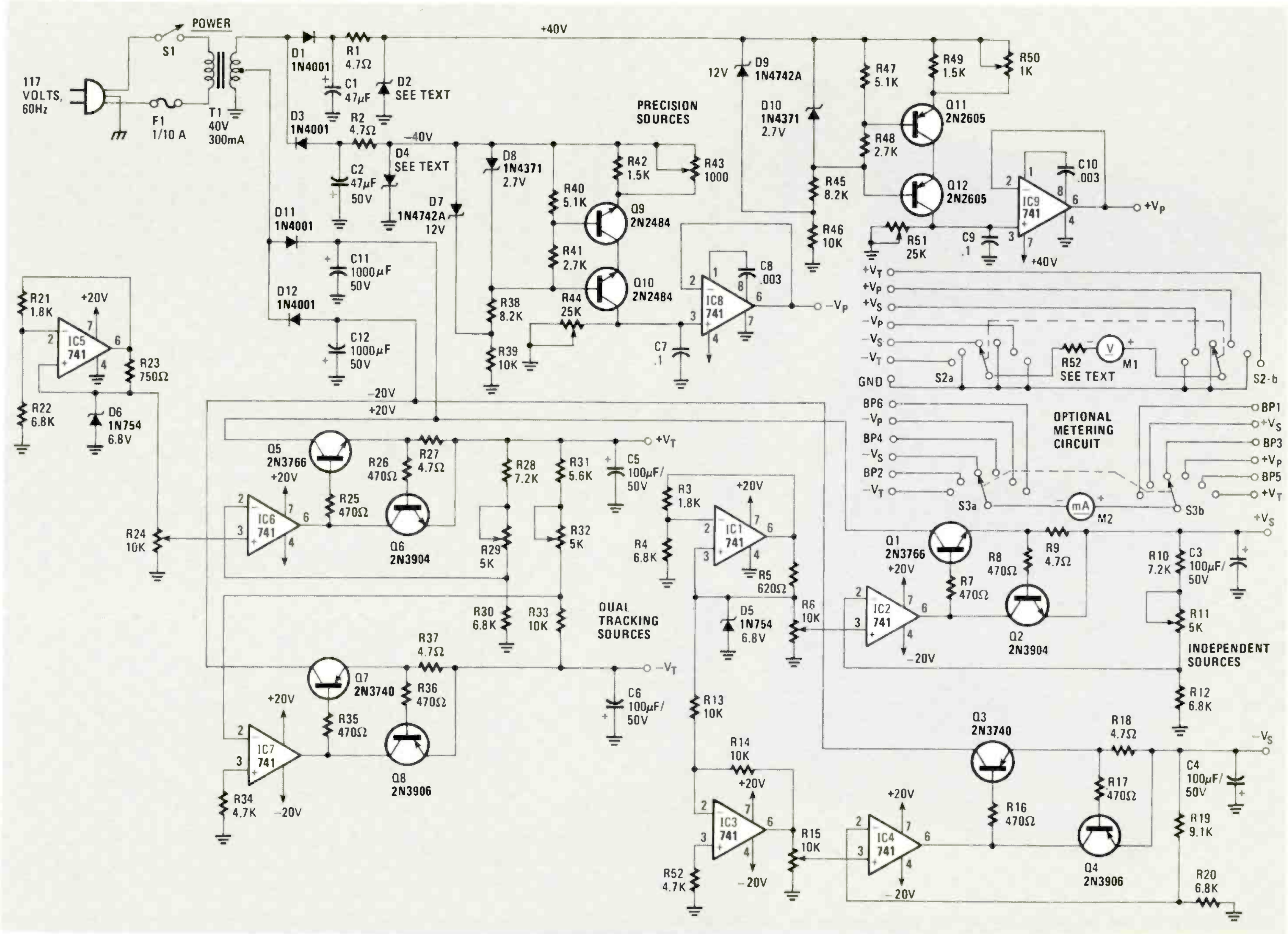


FIG. 1—THE SCHEMATIC shows that the power supply is made up of three Independent pairs of voltage sources, a rectifier circuit, and a metering circuit.

parentheses comes out to about 2.42. E_{IN} is the reference voltage dropped across potentiometer R6. So the output voltage may vary, according to the position of R6, from 0 × 2.42 = 0 volts to 6.8 × 2.42 = 16.5 volts.

The op-amps provide current limiting, and series-pass transistor Q1 provides current amplification. Transistor Q2 senses the output voltage, and, as part of IC2's feedback loop, helps compensate for variations in load current.

The negative independent supply is composed of IC3, IC4 and associated circuitry. Its reference voltage is taken from D5, the same 6.8-volt Zener used in the positive-output circuit. Here, however, the reference is applied to the inverting input of IC3. Due to the ratio of R13 to R14, that op-amp has a gain of −1. Therefore IC3 has a −6.8-volt output that is applied to front-panel −SUPPLY control potentiometer R15. From that point on, the negative circuit operates just as the positive circuit does. The output voltage is determined by multiplying the input voltage by the factor (R19 + R20)/R20. Note that PNP series-pass transistors are used here, while NPN transistors are used in the positive supply.

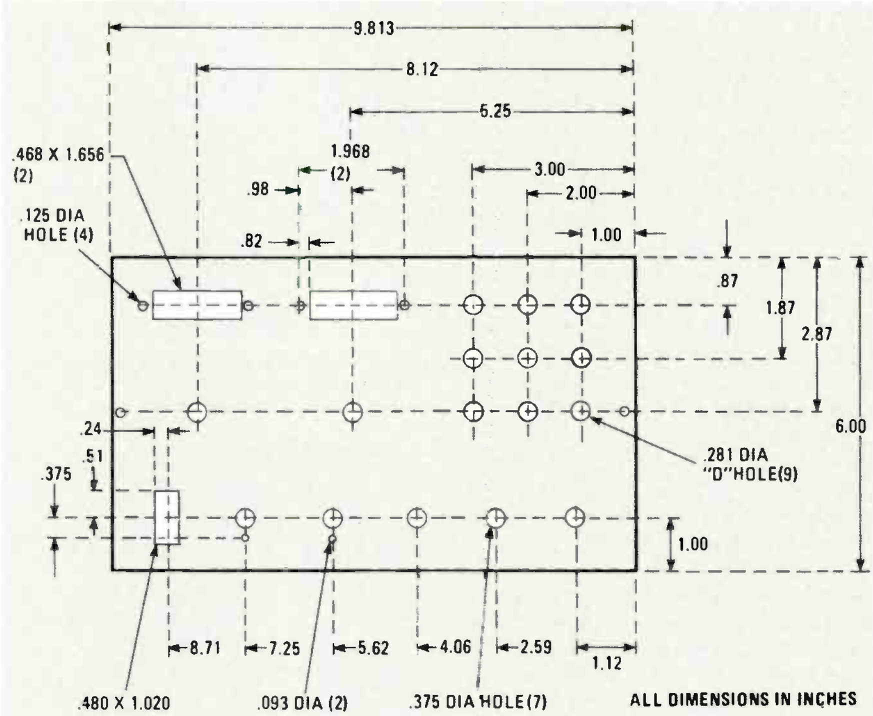


FIG. 2—FRONT-PANEL LAYOUT of the power supply. The hole-sizes for the ten-turn potentiometers and turn-counting dials you use may differ from those given here.

Dual-tracking supply

The dual-tracking supplies operate in a manner similar to that of the independent supplies. A 6.8-volt reference is derived from Zener diode D6 and applied to the non-inverting input of IC5, which functions just as IC1 does. Its output is dropped across front-panel $\pm V_T$ potentiometer R24. The output of R24 is then applied to non-inverting amplifier IC6, which functions just as IC2 does. IC7 is slaved to the output of the positive portion of the circuit, and thereby provides the tracking action that produces an output equal in magnitude but opposite in polarity.

Precision output supplies

Zener diode D9 establishes a 12-volt bias on the bases of a pair of complementary transistors, Q11 and Q12. That bias produces a constant 1-ma current through the collector circuits of the two transistors. The magnitude of that current may be adjusted by R50. The voltage developed across R51 by that current is fed to the non-inverting input of IC9, which is used as a voltage follower (an amplifier with a voltage gain of +1). Here IC9 also provides current amplification. The op-amps used in this circuit can provide a maximum current of about 4 ma.

The non-inverting input of IC9 has an input impedance of at least 10 megohms, so very little of the 1-ma current generated by transistors Q1 and Q2 leaks through that point. Of course, 1 ma through 25K potentiometer R51 will provide a 25-volt drop. As more and more of the resistance

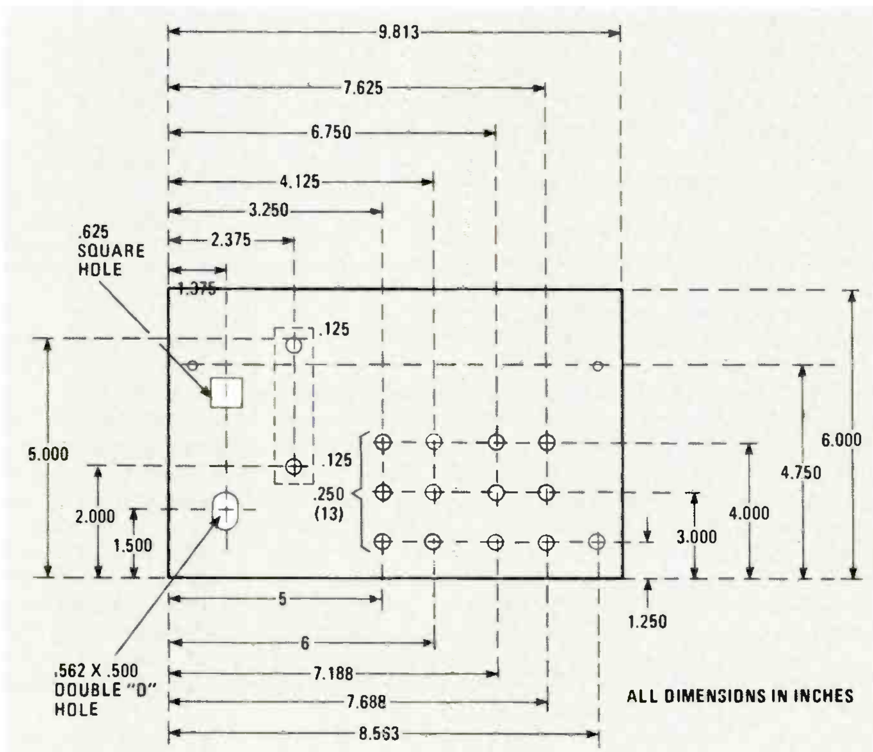


FIG. 3—REAR-PANEL LAYOUT of the power-supply. Note the small holes along the bottom for adjusting the trimmer potentiometers.

of the potentiometer is shunted to ground, the voltage presented to the op-amp decreases proportionately and so, therefore, does the output voltage. For example, when R51 measures 10K (from the non-inverting input of the op-amp to ground), output voltage would be 0.001 ma × 10,000 ohms = 10 volts.

The negative precision source is quite similar to the positive source, except that NPN transistors are used for the 1-ma current source, and the polarity of the Zener diodes is reversed. Op-amp IC8 functions as a voltage follower, as IC9 does in the positive output circuit. The output voltage is adjusted by R44, the front-panel $-V_P$

control. While R44 and R51 are specified as 10-turn 25K potentiometers, 10K units can be used if ± 10-volt outputs are sufficient.

Metering circuits

The meter circuit shown in Fig. 1 is optional. If you choose to omit all metering, just run leads from the output pads on the PC board to the appropriate binding posts. If you choose to include the current-metering circuit, understand that, with the switching arrangement shown, only one supply at a time may be used; the unused supplies will be disconnected from the binding post outputs. Although 12-position dual-gang switches were used in the prototype, you can use any switches with at least 6 positions and 2 gangs. On the other hand, you could add separate meters for each output circuit.

The value of R52 will be determined by the meter you use for M1. It will not be necessary at all if you use a meter with a voltage rating greater than that of the highest output. For the meter specified in the Parts List, a value of 1.8K is adequate, and gives a full-scale reading of 40 volts.

Construction

Most components are easily obtainable from common sources; some hints are provided for those few components which may prove difficult to find. The cabinet specified in the Parts List is roomy enough that it should allow a heftier transformer and output transistors to be used to increase the power supply's current-output capacity.

Figures 2, 3, and 4 show the dimensions of the front, rear and bottom panels of the enclosure. Although hole diameters are provided, be sure you check the manufacturer's specifications for the dimensions of the parts you'll be using before drilling. The shafts for the potentiometers will probably be either ⅛ or ¼ inch. Two-inch edge-reading meters were selected to give the front panel an uncluttered look. You can, of course, use other meters. The square hole in the back panel accommodates a rather fancy fuse holder; you may find it more convenient to use a standard round fuse holder with a 0.440-inch diameter.

Mounting potentiometers and dials

When buying components, be sure to select a dial that matches the potentiometer's shaft diameter. To mount the potentiometers and dials, refer to Fig. 5 and follow the procedure described below, adapted from instructions prepared by Beckman Instruments for the *Helipot Duodial* series of potentiometers and turns-counting dials which were used on the prototype.

- Turn the potentiometer shaft against its counterclockwise stop and insert the shaft into the shaft hole.

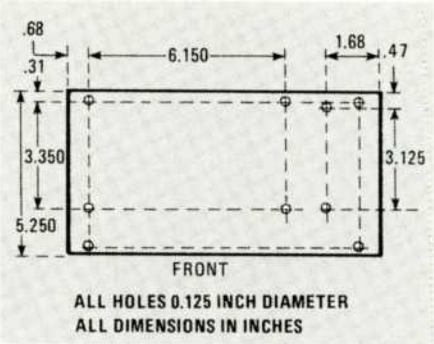


FIG. 4—TOP VIEW of the power supply chassis shows the mounting holes for the PC board, transformer, and cabinet feet.

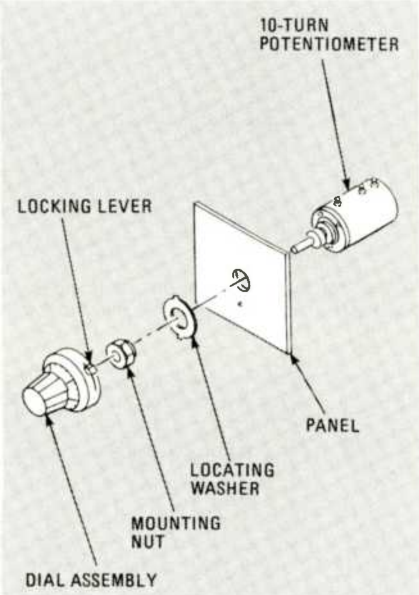


FIG. 5—MOUNTING A MULTI-TURN DIAL and potentiometer can be difficult if you don't follow the instructions carefully.

- Slip a locating washer over the shaft, and seat the locating-washer lug in the small hole beneath the shaft hole.
- With a wrench, firmly tighten the mounting nut into the potentiometer bushing. Note that the nut supplied is reversible. For thick panels, use as shown in Fig. 5. For thin panels, reverse the nut.
- With the locking lever in the OFF (up) position, slip the dial assembly over the potentiometer shaft. Be sure that the lug at the top of the locating washer seats in the slot behind of the dial. Also be sure that the whole assembly rests lightly against the panel.
- Turn the dial counter-clockwise until the zero of the outer scale is in the center of the window. Now turn the dial slowly until the scale reads between 10 and 20 at the index line. Tighten the set screw until a very slight drag on the shaft is felt. Turn the knob very slowly until both zeros line up with the index line. Tighten the set screw firmly.

The PC board

The recommended way to build the power supply is to use a printed-circuit board. Full-size foil patterns for a suitable board are shown in the "PC Service" section. (See page 83.) If you choose not to make your own board, you can purchase an etched and drilled board from the source mentioned in the Parts List. Whichever board you use, check it carefully for shorts and broken traces *before* you mount any components. Be particularly careful when you check areas that will be hidden under components

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.
R1, R2, R9, R18, R27, R37—4.7 ohms
R3, R21—1800 ohms
R4, R12, R20, R22, R30—6800 ohms
R5—620 ohms
R6, R15, R24—10,000 ohm panel-mount potentiometer
R8, R16, R17, R25, R26, R35, R36—470 ohms
R10, R28—7200 ohms
R11, R29, R32—5000 ohms, 15-turn, PC-mount trimmer potentiometer
R13, R14, R33, R39, R46—10,000 ohms
R19—9100 ohms
R23—750 ohms
R31—5600 ohms
R34—4700 ohms
R38, R45—8200 ohms
R40, R47—5100 ohms
R41, R48—2700 ohms
R42, R49—1500 ohms
R43, R50—1000 ohm, 10-turn PC-mount trimmer potentiometer
R44, R51—25,000 ohm, 10-turn panel-mount potentiometer
R52—See Text
Capacitors
C1, C2—47 µF, 50 volts, electrolytic
C3, C4, C5, C6—100 µF, 50 volts, electrolytic
C7, C9—0.1 µF
C8, C10—0.003 µF
C11, C12— 1000 µF, 50 volts, electrolytic
Semiconductors
IC1-IC9—LM101, or LM741 op-amp
D1, D3, D11, D12—1N4001
D2, D4—See Text
D5, D6—1N754 6.8-volt Zener
D7, D9—1N4742A 12.0-volt Zener
D8, D10—1N4371 2.7-volt Zener
Q1, Q5—2N3766
Q2, Q6—2N3904
Q3, Q7—2N3740
Q4, Q8—2N3906
Q9, Q10—2N2484
Q11, Q12—2N2605
Other Components
F1—Fuse ⅒ amp, 250 volts
S1—SPST, 115 volts AC, 1 amp
S2, S3—6-position, 2-pole rotary switch
BP1-BP9—Binding posts
Miscellaneous: Turns-counting dials (2); Cabinet: Bud No. SE3030; heatsinks for Q1, Q3, Q5, and Q7; line cord, hookup wire, etc.
Note: An etched and drilled PC board is available from Specialty Electronic Services, Inc., P.O. Box 3320, San Antonio, TX 78211, for $48.50 postpaid.

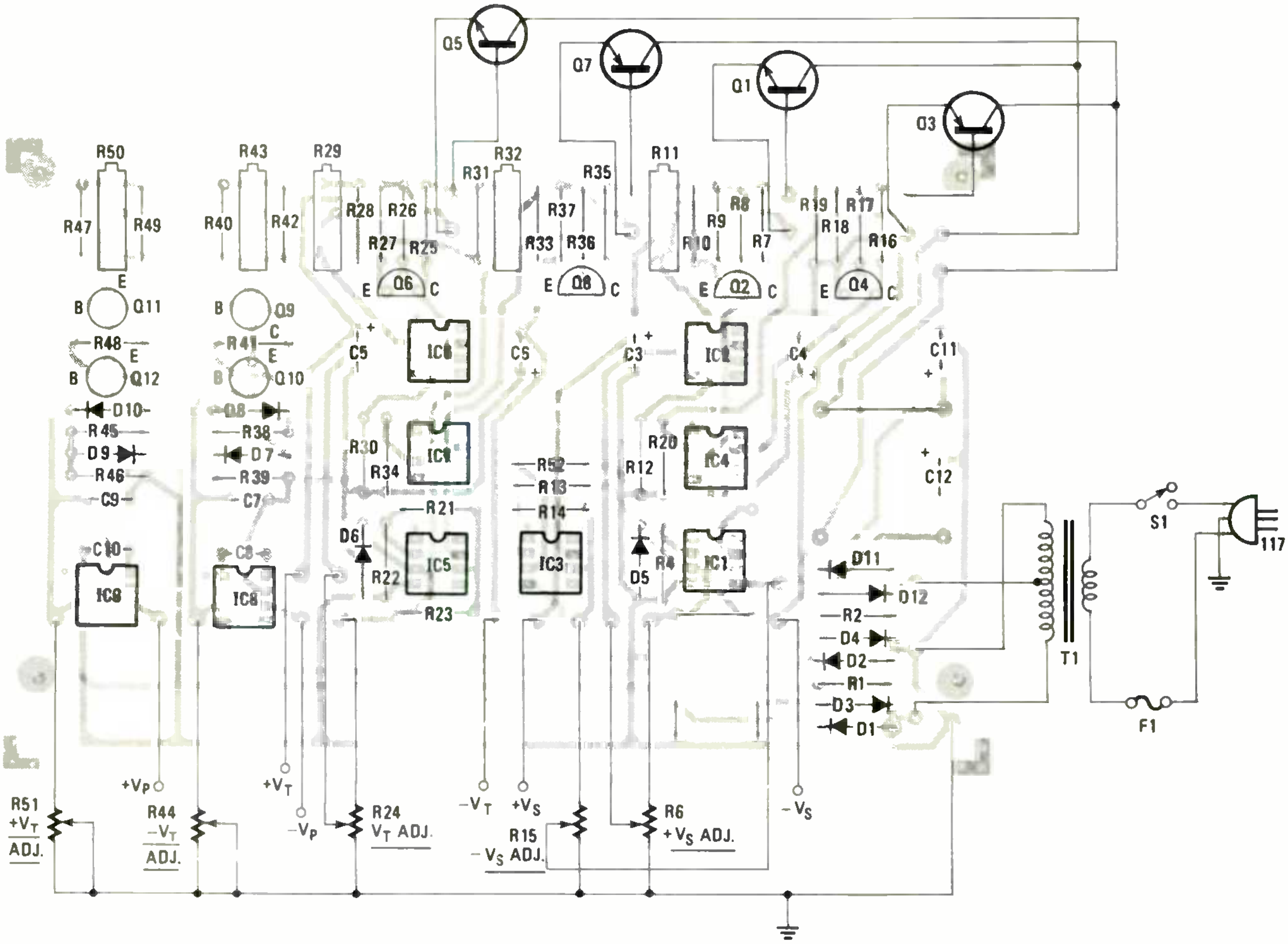


FIG. 6—PARTS PLACEMENT DIAGRAM shows how on-board and off-board components are wired.

once they're mounted on the PC board.

After checking your board and correcting any problems, you can mount the components using the parts-placement diagram in Fig. 6 as a guide. Be sure to observe the polarity of all semiconductors and electrolytic capacitors. Use sockets for the op-amps, but don't insert the op-amps at this time. Orient the small transistors (Q2, Q4, Q6, Q8-Q12) and diodes on the PC board carefully.

Transistors Q1, Q3, Q5, and Q7 require heat sinks, and should be mounted to the chassis. Be sure to use mica insulators so that their collectors won't short to the chassis; and coat the insulators on both sides with silicone grease to ensure efficient heat transfer. Attach the complete assemblies to the rear panel.

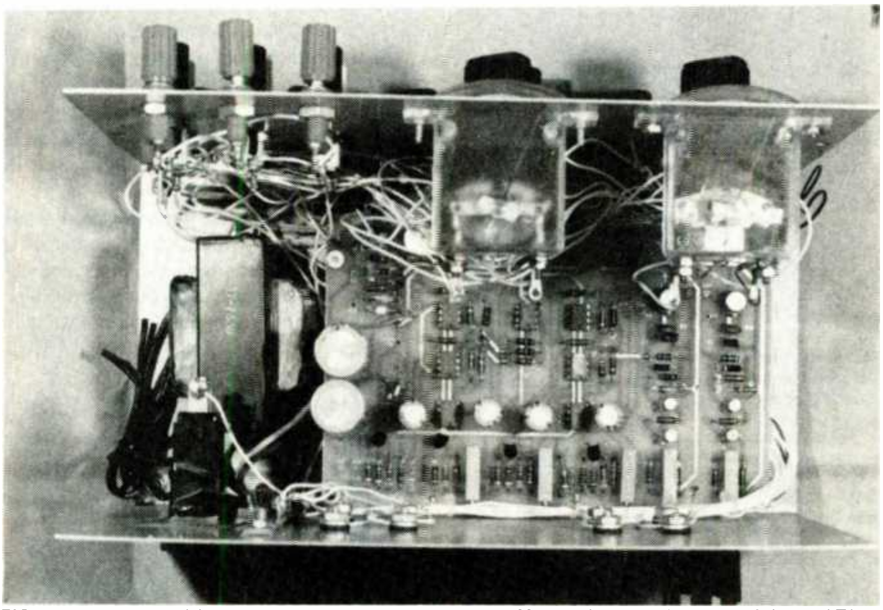


FIG. 8—INTERNAL ASSEMBLY of the power supply. M1 and M2 are shown at the upper right, and T1 at the lower left.

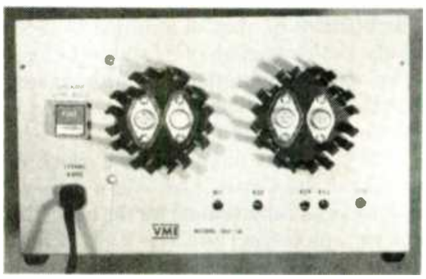


FIG. 7—THE REAR PANEL OF THE POWER SUPPLY.

Final assembly

After all components have been mounted, but before the IC's have been installed in their sockets, check the board carefully for solder bridges and unsoldered pads. Fix any problems, and then connect the transformer to the PC board. Verify the presence of +40 and

Continued on page 133

MICHAEL RINGENBERGER

PHONY BURGLAR ALARM

Scare off burglars without emptying your wallet with this simple, inexpensive electronic "scarecrow."

IT'S A SAD COMMENTARY THAT THESE days a burglar alarm is becoming as common a household "appliance" as a refrigerator or a dishwasher. But burglar alarms are not inexpensive. Most will cost a few hundred dollars, and some elaborate systems could cost a thousand dollars or more.

If your household possessions are simply not worth that kind of outlay, there is a very inexpensive alternative. Most burglars are burglars because it's the easiest way they know of to make a fast buck. When they look for a house to ransack, they try to find the easiest target. The trick, then, is to make your house *look* like it is protected by a sophisticated alarm system. That can be done for less than $20 with the circuit described here.

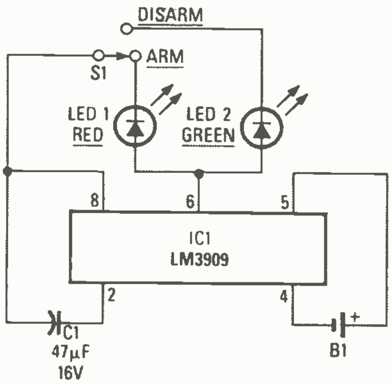


FIG. 1—IT'S NOT A REAL BURGLAR ALARM, but this "electronic scarecrow" can do almost as good a job as a real one when it comes to scaring away a burglar.

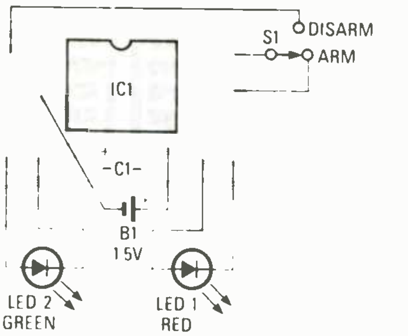


FIG. 2—THE CIRCUIT CAN BE BUILT on a tiny PC board. The pattern is provided in our PC Service section.

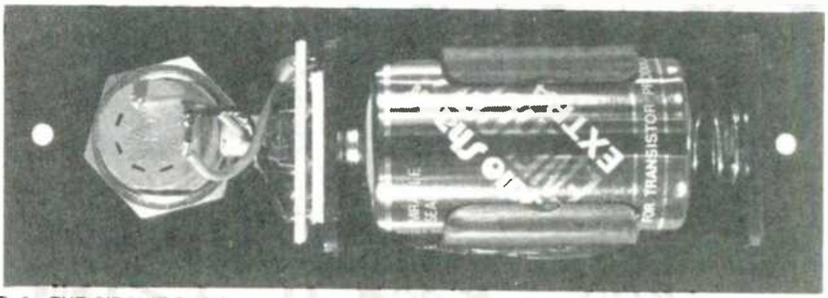


FIG. 3—THE CIRCUIT SHOULD be assembled on a piece of anodized aluminum.

An electronic scarecrow

No burglar alarm will make your home absolutely burglar proof. If you have something a burglar wants badly, and the burglar is a professional, he'll find a way to defeat the alarm. Otherwise, an alarm's principal value is as an "electronic scarecrow." Seeing that the house is protected, a burglar will move on to easier pickings.

How does a burglar know that there is an alarm? Most alarm systems have their sensors hidden from view, so frequently the only sign of an alarm system is a status display located near the entrance. That display usually consists of a red and a green LED that show whether or not the system is armed.

By now you may have guessed where we are headed: Since the presence of an alarm-status display alone is enough sometimes to scare off a burglar, why not set up a dummy display and do away with the rest of the system? That's precisely what our circuit does. Of course it won't give you the degree of security that a real alarm-system would, but its cost is much, much lower.

The schematic diagram of the circuit is shown in Fig. 1. The circuit is extremely simple and is built around an LM3909 LED flasher IC. With the value of C1 shown, the circuit will flash an LED at a rate of 5.5 times-per-second. It is powered by an alkaline "C"-size cell; estimated battery life is 15 months.

Switch S1 should be a key type as is typically found in burglar-alarm installations. The switch should be mounted on the dummy status-display's front panel to give the set up a more realistic look.

PARTS LIST

C1—47 µF, 16 volts, electrolytic
IC1—LM3909 LED flasher IC
LED1—green jumbo LED
LED2—red jumbo LED
S1—SPST, key switch
B1—1.5 volts, "C" cell
Miscellaneous: PC or perforated-construction board, anodized aluminum panel, battery holder, wire, solder, etc.
The following are available from Enberg Electronics, PO Box 55087, Indianapolis, IN 46205: Complete kit, including anodized aluminum cover, $18.95; assembled unit, $22.95; anodized cover, $2.50; PC board, $2.50. Indiana residents please add 5% sales tax.

Building the circuit

The circuit is simple enough to be built on a piece of perforated construction board. If you wish to use a PC board, an appropriate pattern is shown in our PC Service section. The parts-placement diagram for the board is shown in Fig. 2.

Two construction details bear special mention. One is the lead length of the LED's. They should be ¼-inch long to allow for flexibility when mounting the board (more on that in a moment). Secondly, the lead length of C1 should be kept to an absolute minimum. Be sure that the bottom of that electrolytic capacitor is flush with the board.

The circuit is mounted on a piece of anodized aluminum. Size is not critical, as long as it is appropriate for the task. The author's prototype was 1½ × 4 inches. The other side of the aluminum piece will serve as the dummy status-panel.

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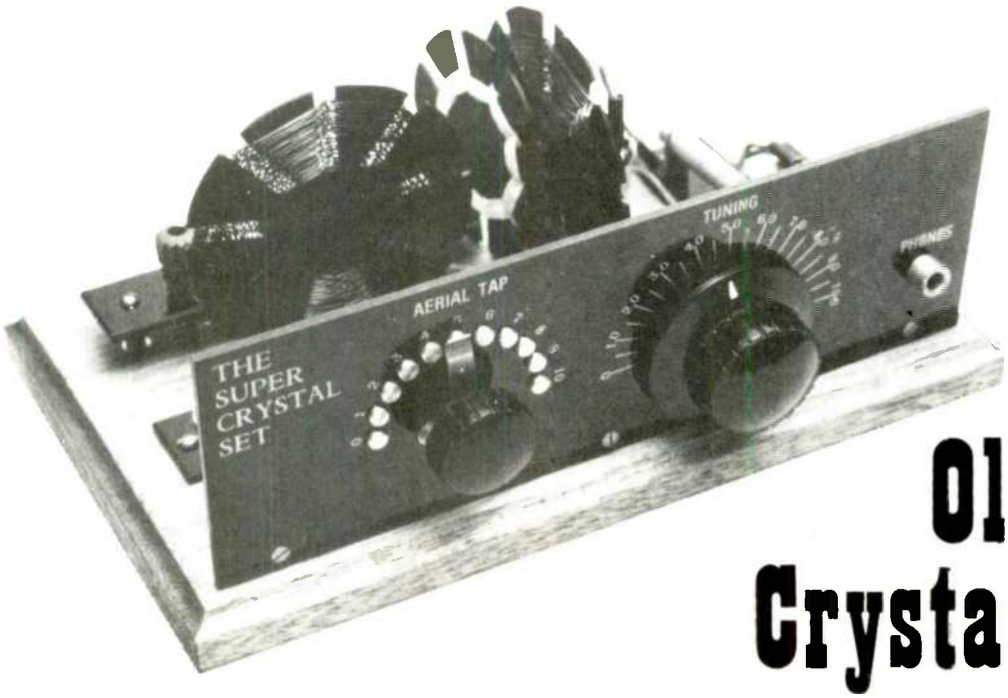

Old-Time Crystal Radio

Here's how to build a vintage-style crystal radio receiver with performance that might surprise you.

PAT O'BRIAN

EVERY ELECTRONICS HOBBYIST HAS BUILT a crystal set. What? *You* haven't? Then this vintage-style crystal radio is the one to build! It's a high-performance receiver that tries its best to remain true to its era.

Crystal radios capture the imagination because they need no power source and they bring back the days when radio was "magic." There is, of course, nothing magic about a crystal set that works well. But careful design can make a receiver something special. This design uses the signals captured by the antenna very efficiently. Of course, the attractive polished wood base helps make the receiver special, too—even to those who aren't usually fascinated by the "magic" of crystal radios.

A high-performance circuit

The schematic of the receiver is shown in Fig. 1. One of the features of the design is that the antenna-tuning circuit is separate from the main frequency-selection circuit. The antenna-tuning circuit is made up of an 80-turn, 10-tap coil (L1), a coupling coil (L2), and an optional fixed capacitor (C1). It acts as a pre-selector for the main tuning circuit. In other words, it maximizes the strength of the signals received by the antenna at a particular frequency or frequency band.

The inductance of L1 is varied by selecting one of the coil's taps. The energy from the antenna-tuning circuit is inductively coupled to the main tuning circuit via L2 and L3. The degree of coupling is variable. As shown in the photo in Fig. 2, L2 can pivot about its mounting point. The variable coupling results in a more selective receiver.

The main tuning circuit is made up of L3 and C2. RF energy from that tank circuit is tapped off by S2 and detected by D1. Switch S2 isn't a conventional switch. Instead, it is an alligator clip that is moved from tap to tap. The detected audio signals are fed to jack J1, and then to a pair of high-impedance (4000 ohm) headphones. Capacitor C3 acts to bypass RF past the headphones, which must be a high-impedance type.

Building the receiver

How you build your receiver is, of course, a personal choice. But we'll show you what we think is the right way to do it. If you lack the skills or the materials that are needed to put together an authentic-looking crystal radio, then you might be better off buying the kit that's available from the source mentioned in the Parts

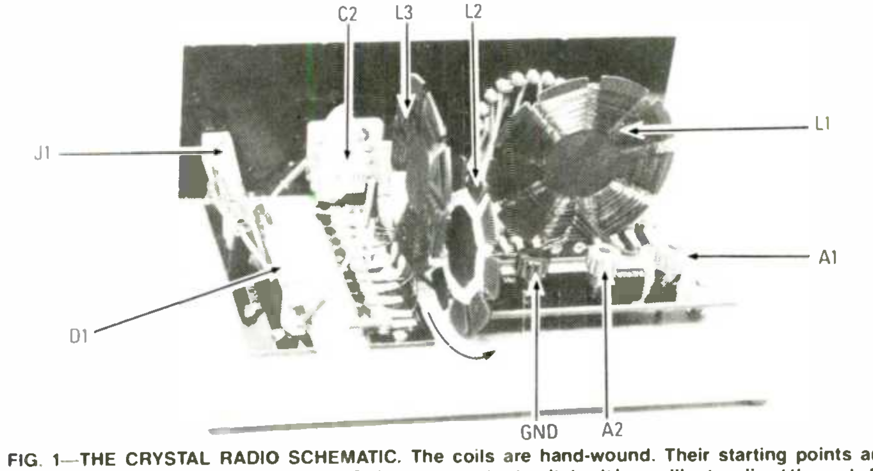

FIG. 1—THE CRYSTAL RADIO SCHEMATIC. The coils are hand-wound. Their starting points are indicated by bold dots. Note that switch S2 is not a standard switch—it is an alligator clip at the end of a "flying lead."

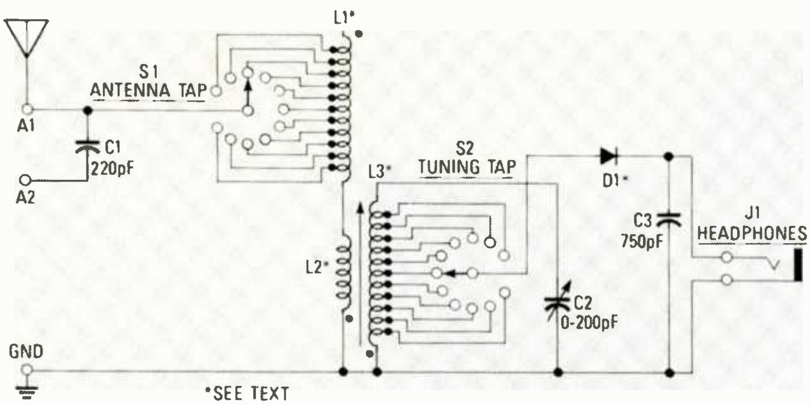

FIG 2—REAR VIEW of the crystal set shows how the components are mounted on bakelite panels, which are in turn mounted to the hardwood base. Note that the coupling coil, L2, pivots around its mounting point so that its degree of coupling to L3 can be adjusted. Also note the case in which D1, the crystal detector, is mounted.

List. (The receiver shown in the photos was built from a kit.) If you choose to put yours together from scratch, don't hesitate to change our layout to suit the components you find. Just try to keep the flavor of the past by following our prototype and by using using things like brass screws, DCC (*Double Cotton Coated*) wire, bakelite mounting panels, etc.

Before we can build the receiver, we have to get all the components together. It will take some scrounging but it can be done. The best place to start is with the components you'll have to make yourself: the three "spider-web" coils.

Winding the spiderweb coils is perhaps the most difficult part of building the receiver. It's actually not that difficult if you follow our directions carefully. Two of the coils, L1 and L3, are wound identically. They consist of 80 turns of 26-gauge enamel-coated wire wound on a 9-spoke spiderweb coil form with a diameter of 4¼ inches.

The coil is wound as ten separate 8-turn coils. After they are wound, they are connected together—the connections become the taps. Figure 3 shows what your coil form should look like, and indicates some of the winding specifics.

PARTS LIST

D1—1N34A germanium. See text
C1—220 pF, mica
C2—0–200 pF, variable
C3—750 pF, mica
L1, L3—80 turns of 26-gauge wire on spider-web form. See text.
L2—16 turns of 26-gauge wire on spider-web form. See text.
J1—phone jack, ¼ inch
Miscellaneous: Hardwood base, coil forms, 26-gauge wire, binding posts, rubber mounting feet, high-impedance headphones, etc.

NOTE: A complete kit for the crystal receiver (order No. K-9002) is available from Dick Smith Electronics, Inc., P.O. Box 8021 , Redwood City, CA 94063, 800-332-5373 (orders) 415-368-8844 (inquiries) for $79.95 plus $5.50 handling. High-impedance vintage (1940) headphones (order No. C-4001) are available for $19.95 plus $2.50 shipping. California residents must add 6.5% sales tax.

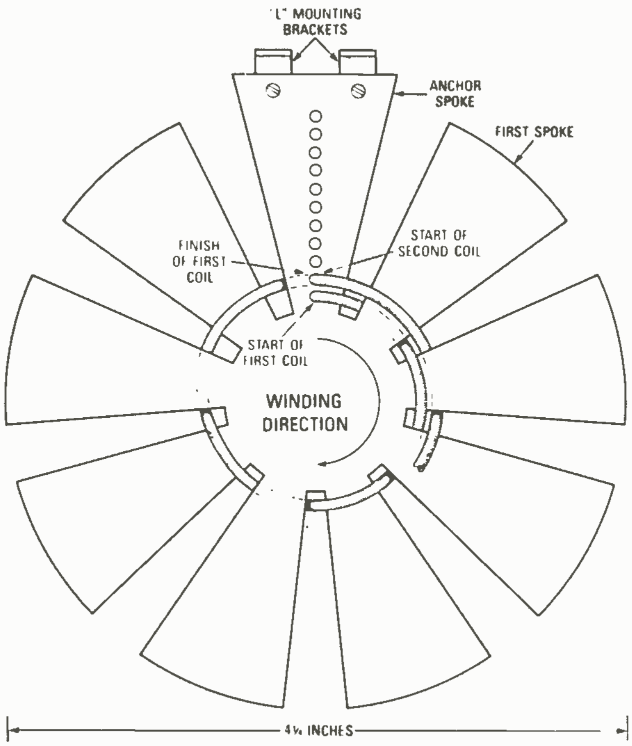

FIG. 3—THE SPIDER-WEB COILS must be hand wound. Here, shown half size, is the coil form for L1 and L3. Each coil consists of 80 turns of 26-gauge enamel-coated wire, tapped every 8 turns. However, as explained in the text, they are wound as ten separate 8-turn coils. Coil L2 is wound as 16 turns of 26-gauge cotton-coated wire on a 3¾-inch form. Use stiff, black cardboard to make the forms.

The coils are wound from the "front" of the coil forms, which is the side where the "L" mounting brackets are attached. Start at the inside of the coil and work outward. To start each 8-turn coil, feed about 10 inches of wire through the appropriate hole from the front of the form, taking it around the right side of the mounting spoke (which we'll call the anchor spoke), and feeding it again through the same hole and pulling it tight. That anchors the start of each coil in place. Now wind the wire around the coil form, under the first spoke, over the second, under the third, and so on.

The "finish" end of the coil is pushed through the next hole toward the outside of the form, and it is anchored to the spoke by bringing the wire around the the *left* side of the mounting spoke and through the hole and pulling it tight.

The start of the next coil is anchored at the hole where the preceding coil ended. Be sure to wind the coils tightly so that a total of 80 turns will fit on the coil form, and so that you don't cover holes on the anchor spoke.

When all ten 8-turn coils are wound correctly on the coil form, you should be left with 9 pairs of wire, and two single wires (the start and end). Twist each pair together tightly, and cut to an appropriate length. Solder the 9 pairs together, and tin the start and finish leads. You'll have to apply a good amount of heat from the soldering iron because you need to melt the enamel coating. If you do it right, you won't have to scrape the leads bare. You can check your work by measuring con-

continued on page 134

STUN GUN

ROBERT GROSSBLATT, and ROBERT IANNINI

This experimental high-voltage generator can produce 75,000 volts at a peak power of 25,000 watts.

Man's fascination with high voltages began with the first caveman who was terrified by a bolt of lightning. In more recent times, electronics experimenters and hobbyists have found the Tesla coil and the Van de Graaff generator equally fascinating. In this article we'll show you how to build a hand-held high-voltage generator that is capable of producing 75,000 volts at a power level as high as 25,000 watts. The stun gun can be used to demonstrate high-voltage discharge and as a weapon of self-defense. Before building one, however, you should read and pay very close attention to the warning in the accompanying text box, as well as to the description of physiological effects that follows.

WARNING

THIS DEVICE IS NOT A TOY. We present it for educational and experimental purposes only. The circuit develops about 75,000 volts at a maximum peak power of 25,000 watts. The output is pulsed, not continuous, but it can cause a great deal of pain should you become careless and get caught between its output terminals. And you should never, repeat, NEVER, use it on another person! It may not be against the law in your area to carry a stun gun in public, but, if you use it on another person, you may still be liable for civil action.

To help you build, test, and adjust the device safely, we have included a number of tests and checks that must be followed strictly. Do not deviate from our procedure.

Physiological effects

So that you may understand the danger inherent in the stun gun, let's discuss the physiological effects first. When a high voltage is discharged on the surface of the skin, the current produced travels through the nervous system by exciting single cells and the *myelin sheaths* that enclose them. When that current reaches a synapse connected to a muscle, it causes the muscle to contract violently and possibly to go into spasms.

The longer contact with the high voltage is maintained, the more muscles will be affected. If the high voltage maintains contact with the skin long enough to cause muscle spasms, it may take ten or fifteen minutes before the brain is able to re-establish control over the nerve and muscular systems.

How much power is required to cause such spasms? That's not an easy question to answer because, although it is relatively easy to make precise measurements of the power produced by a high-voltage device, it is difficult to rate the human body's susceptibility to shock accurately. Some obvious factors include age and diseases such as epilepsy. But the bottom line is simple: *The only one who fools around with a stun gun is a fool.*

The amount of energy a device delivers is actually the amount of power delivered in a given period of time. For our purposes, it makes sense to talk about energy in joules (watt-seconds). Using a fresh 9.8-volt Ni-Cd battery, the stun gun is capable of delivering peak power pulses of 25,000 watts. Actually, pulses start out at peak power and then decay exponentially. The length of the decay time depends on the components used in the circuit, the ambient temperature, the battery's capacity, and the positioning of the output contacts with respect to each other.

Assuming that the decay rate is purely exponential, the stun gun can produce about 0.5 joules of energy, provided that the battery is fully charged. Let's put that number in perspective.

Both the Underwriter's Laboratory (in Bulletin no. 14) and the U. S. Consumer Product Safety Commission state that ventricular fibrillation (heart attack) can be caused in humans by applying 10 joules of energy. Since the stun gun only generates about half a joule, you might think that a device that produces only one twentieth of the critical amount has a more-than-adequate margin of safety. *Don't bet on it.* A brief contact with the stun-gun's discharge hurts a great deal, but it takes only about five seconds of continuous discharge to immobilize someone completely.

Let's compare the stun gun's output with a similar device, called a Taser gun, which appeared on the market a few years ago. You may have seen a film demonstrating just how effective the Taser could

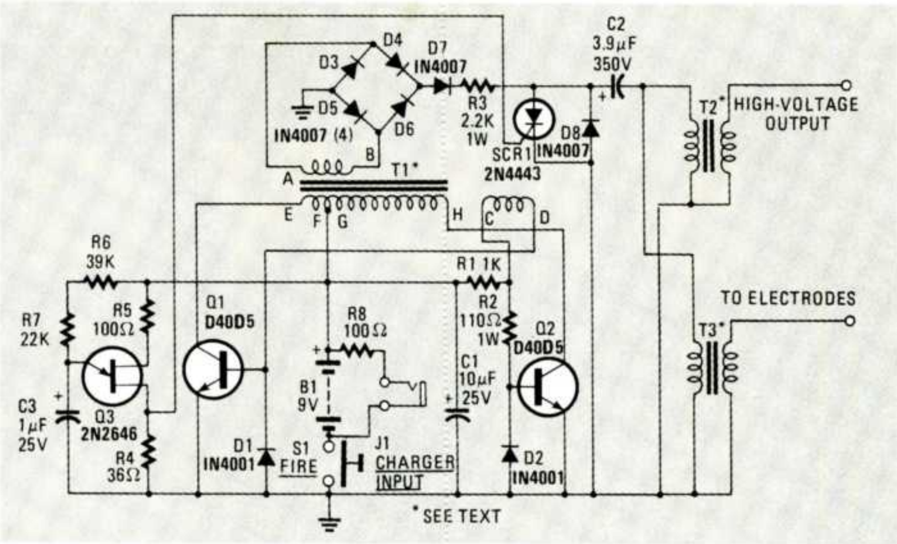

FIG. 1—THE STUN GUN'S CIRCUIT is a multi-stage voltage step-up circuit. The Q1/Q2 circuit produces a squarewave output of about 10 kHz, and Q3 produces 15-µs discharge pulses at a rate of about 20 ppm. Those pulses fire SCR1, which induces a voltage in the windings of step-up transformers T2 and T3.

be as a deterrent. A foolhardy volunteer was paid an enormous sum of money to have the Taser fired at him. No matter how big, strong, (and stupid) the person was, as soon as the Taser's "darts" hit him, he would collapse to the ground and go into uncontrollable convulsions.

The energy produced by the Taser is only 0.3 joules—about 60% of what our stun gun produces! Even so, the Taser has been officially classified as a firearm by the Bureau of Tobacco and Firearms because it shoots its electrode "darts" through the air. Even though our stun gun doesn't operate that way, the Taser puts out considerably less energy than the stun gun. Keep those facts and figures in mind as you assemble and use the device.

How it works

The schematic diagram of the stun gun is shown in Fig. 1. Basically, it's a multi-stage power supply arranged so that each succeeding stage multiplies the voltage produced by the preceding stage. The final stage of the circuit feeds two oppositely-phased transformers that produce extremely high voltage pulses. If that description sounds familiar, you've probably studied capacitive-discharge ignition systems—the stun gun works on the same principles.

The first section of the power supply is a switcher composed of Q1, Q2, and the primary windings (connected to leads E, F, G, and H) of T1. When FIRE switch S1 is closed, R1 unbalances the circuit and that causes it to start oscillating. Since base current is provided by a separate winding of T1 (connected to leads C and D), the two transistors are driven out of phase with each other, and that keeps the circuit oscillating. Resistor R2 limits base drive to a safe value, and diodes D1 and D2 are steering diodes that switch base current from one transistor to the other. Oscillation occurs at a frequency of about 10 kHz.

The switching action of the first stage generates an AC voltage in T1's high-voltage secondary (leads A and B). The amount of voltage depends on the battery used, but a battery of seven to nine volts should produce 250 to 300 volts across T1's secondary.

That voltage is rectified by the full-wave bridge composed of diodes D3–D6. Capacitor C2 charges through D7 at a rate that is controlled by R3.

The value of capacitor C2 affects the output of the stun gun. The greater the capacitance, the more energy that can be stored, so the more powerful the discharge will be. A larger capacitor gives bigger sparks, but requires more charging time, and that gives a lower discharge rate. On the other hand, a smaller capacitor gives smaller sparks, but a faster discharge rate. If you wish to experiment with different values for C2, try 3.9 µF (as shown in Fig. 1), 7.8 µF, and 1.95 µF. Those values were arrived at by using one 3.9 µF capacitor alone, two of the same capacitors in series, and two in parallel.

Meanwhile, UJT Q3 produces 15-µs pulses at a rate of about 20 ppm. That rate is controlled by C3 and the series combination of R6 and R7. When a pulse arrives at the gate of SCR1, it fires and discharges C2. That induces a high-voltage pulse in the primary windings of T2 and T3, whose primaries must be wired out of phase with each other. The result is a ringing wave of AC whose negative component then reaches around and forces the SCR to turn off. When the next pulse from Q3 arrives, the cycle repeats.

The outputs of the stun gun appear across the secondaries of T2 and T3. The hot leads of those transformers connect to

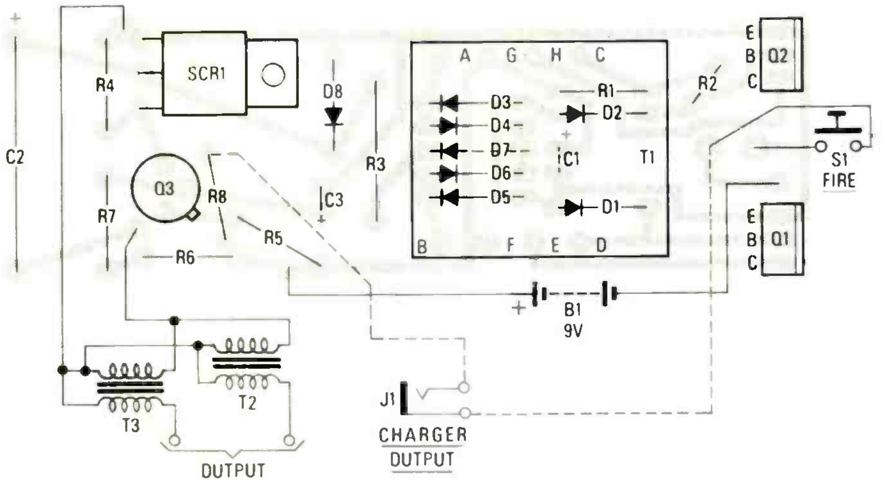

FIG. 2—MOUNT ALL COMPONENTS ON THE PC BOARD as shown here. Note that T2 and T3 are mounted off board, and that J1, C1, and D7 mount on the foil side of the board. In addition, a number of components mount beneath T1: D1–D6, R1, and R3. Those diodes and resistors must be installed before T1.

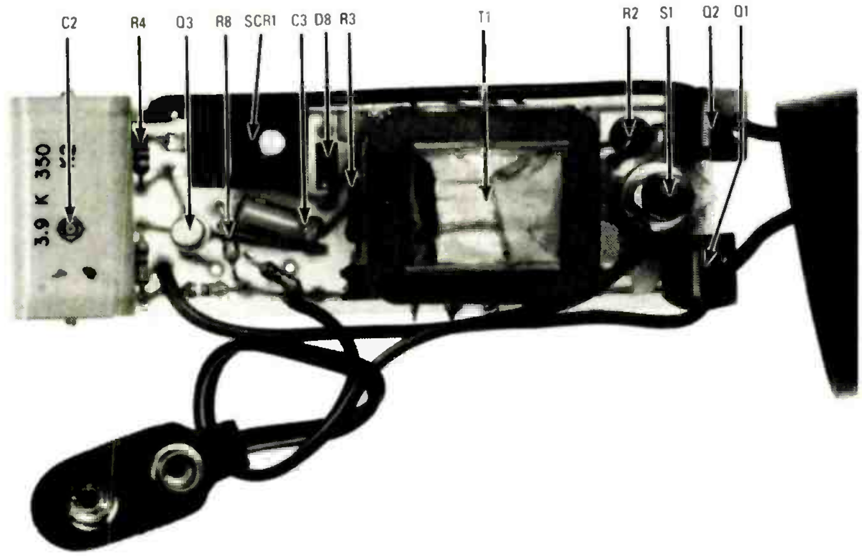

FIG. 3—BEND SCR1'S LEADS 90° so that the nomenclature faces up and then solder the SCR to the board. Also note that C3 must be bent over at a 90° angle, and that R2 is mounted vertically.

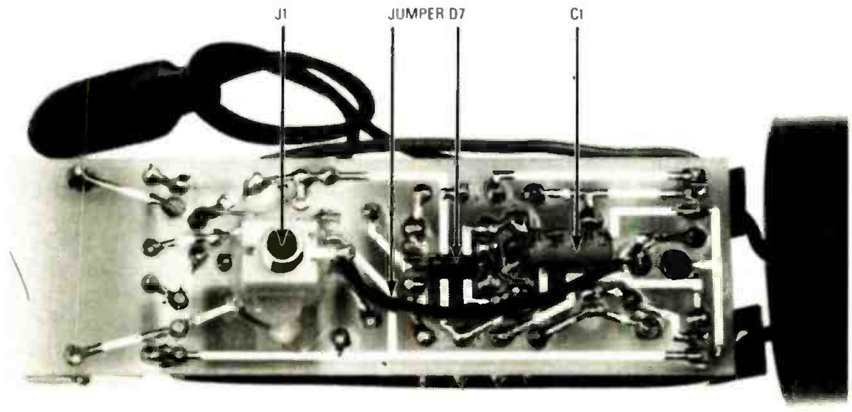

FIG. 4—JACK J1, DIODE D7, AND CAPACITOR C1 mount on the foil side of the PC board. One terminal of J1 mounts to the same pad as R8, and the jack should be glued to the board with RTV (or other high-voltage compound) after you verify that the circuit works properly.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1—1000 ohms
R2—110 ohms, 1 watt
R3—2200 ohms, 1 watt
R4—36 ohms
R5, R8—100 ohms
R6—39,000 ohms
R7—22,000 ohms

Capacitors

C1—10 µF, 25 volts, electrolytic
C2—3.9 µF, 350 volts, electrolytic
C3—1 µF, 25 volts, electrolytic

Semiconductors

D1, D2—1N4001, 50-volt rectifier
D3–D8—1N4007, 1000-volt rectifier
Q1, Q2—D40D5, power transistor
Q3—2N2646, UJT
SCRI—2N4443

Other components

B1—9-volt Ni-Cd battery
S1—SPST momentary pushbutton switch
T1—12 to 400 volts saturable-core transformer. See text
T2, T3—50 kilovolt pulse transformer, 0.32 joules. 400-volt primary. See text

Note: The following components are available from Information Unlimited, P. O. Box 716, Amherst, NH 03031: T1, $12.50; both T2 and T3, $12.50; C2, $1.50; PC board, $4.50; case, $3.50; case with T2 and T3 potted, $17.50; charger, $6.50; 9.8-volt battery, $16.50; complete kit of all parts including all components, PC board, case, and charger, but no battery, $39.50.

the output electrodes, which should be held securely in position about two inches apart, and which should be insulated from each other and from the environment with high-voltage potting compound.

Batteries

The stun gun can be powered with almost any battery that can supply at least seven volts at one amp. A Ni-Cd battery would be a good choice; R8 and J1 will allow the battery to be recharged without removing it from the case.

The higher the battery's voltage, the higher the stun-gun's output voltage. Most nine-volt Ni-Cd's actually have a maximum fully-charged output of only 7.2 volts. However, batteries that deliver 9.8 volts when fully charged are available from several sources.

Construction

Keep in mind the fact that the stun gun produces dangerously high voltages, and don't approach the construction of the stun gun with the same nonchalance with which you might build a light dimmer.

The circuit can be built on a PC board or on perfboard. The foil pattern for a PC

continued on page 135

RADAR SIGNAL DETECTOR

If you think that a sensitive radar detector is a complicated and expensive piece of equipment, have we got a surprise for you!

GREGORY HODOWANEC

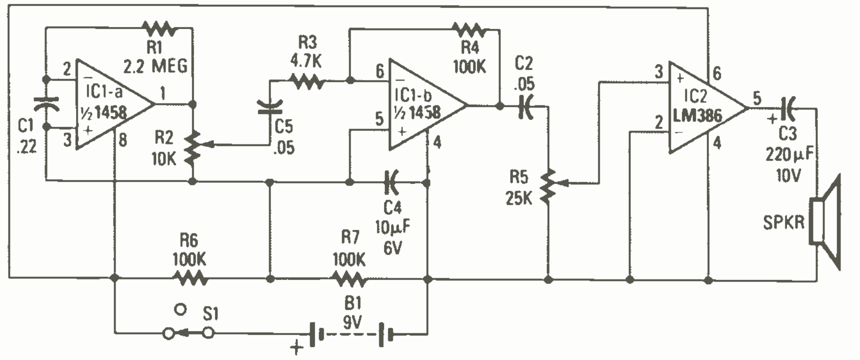

FIG. 2—DELUXE RADAR DETECTOR adds a buffer amplifier and an audio power amp to drive a speaker.

RADAR DETECTORS ARE USUALLY COMPLIcated and expensive devices, but a simple, yet effective, detector can be built in a small plastic case for less than ten dollars! The circuit, which can be tuned to respond to signals between 50 MHz and 500 GHz, is a modified version of the author's gravity-wave detector presented in April's issue. We'll actually present two different circuits, an "economy" and a "deluxe" model.

How they work

The economy model's schematic is shown in Fig. 1, and the deluxe model's schematic is shown in Fig. 2. The main difference between the two circuits is that the economy model simply drives a piezo-electric transducer directly from an op-amp, while the deluxe model uses an LM386 audio power amplifier to drive a small speaker. Doing that allows the extra op-amp stage to be used for additional buffering, and that makes for a more sensitive detector.

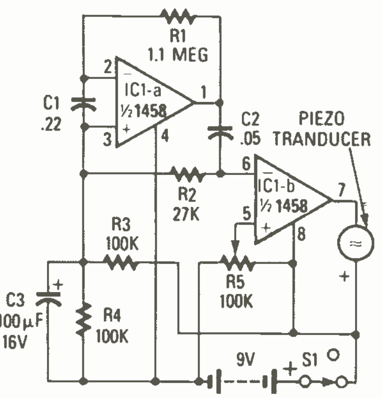

FIG. 1—THE ECONOMY RADAR DETECTOR needs only one IC and a few discrete components.

The first op-amp in each circuit (IC1-*a*) functions as a current-to-voltage converter. Then, in the economy model (Fig. 1), IC1-*b* buffers the output to drive the piezo buzzer. Potentiometer R5 sets the switching threshold of IC1-*b*; normally it is adjusted so that the circuit barely triggers on background noise, then it's backed off a bit. That should provide plenty of sensitivity to incident RF.

Resistors R3 and R4, and capacitor C4, serve to "split" the supply voltage. To get more sensitivity from the detector, those components could be eliminated and two series-connected nine-volt batteries used instead. In that configuration, the junction of the batteries would be connected to the point where R3, R4, and C4 now meet. Alternatively, for mobile operation, twelve volts could be tapped from your car's cigarette-lighter jack.

The deluxe model functions in a similar manner, except that IC1-*b* is configured as a ×20 buffer amplifier to drive the LM386. Potentiometer R2 adjusts threshold here, and potentiometer R5 functions as a volume control.

In both circuits, input capacitor C1 functions as a "transmission-line" that intercepts both electrical and magnetic components of incident radar signals. While it is a low-Q circuit (it is very broadband), the response may be further optimized by trimming C1's lead lengths for the desired frequency, as shown in Fig. 3. To detect typical road-radar systems, the input capacitor's leads should be about 0.5–0.6 inches long.

In both circuits the detector provides a "ringing," or slowly-decaying output with a resonance of about 400–600 Hz for the component values shown. Feedback resistor R1 may be adjusted for another "ring" frequency, if desired.

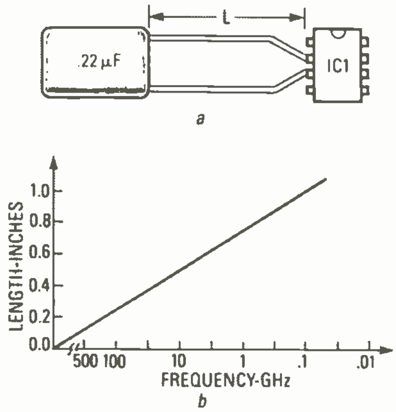

FIG. 3—VARY THE LEAD LENGTHS OF C1 to tune the input circuit.

Construction hints

Whichever detector you choose, build it in a non-metallic case so that incident RF won't be blocked. However, make sure that only R1 provides feedback to the detector's input. Since the gain of the detector is so high, unwanted feedback can force the input stage into continuous oscillation, rather than the "ringing" oscillation that decays in time. Should unwanted feedback become a problem, a small capacitor (0.005–0.01 µF) across resistor R4 may help, as may a 200–500 µF capacitor across the battery.

Perfboard construction is preferable to PC-board construction because reduced wiring capacitance and the absence of a ground plane will reduce the chance of unwanted feedback. Likewise, it's better to use a small *shielded* speaker for output because magnetic (and gravitational) energy from the speaker could feed back to the input. So keep C1 as far from the speaker as possible.

The detector should perform properly with little adjustment. After applying

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WORKING WITH VOLTAGE COMPARATORS

Voltage-comparators and window-comparators are extremely versatile circuits. Here are some practical circuits that you can put to use.

RAY MARSTON

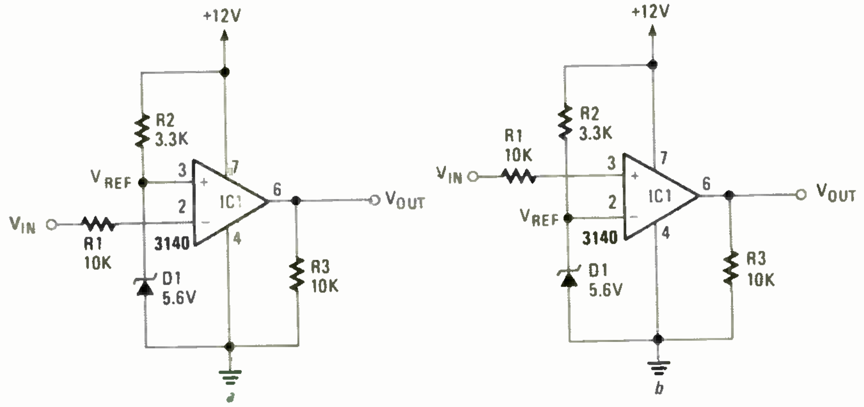

FIG. 1—BASIC VOLTAGE-COMPARATOR CIRCUITS.

WE'RE SURE THAT YOU CAN THINK OF many applications for a voltage comparator: a circuit that abruptly changes its output state when an input voltage crosses a certain reference value. Voltage comparators have plenty of practical applications apart from the obvious ones of over- and under-voltage switches. The number of applications becomes especially apparent when you realize that the voltage can be representing resistance, temperature, light-level, and more.

Voltage comparators can readily be made to activate relays (or alarms, or other circuits) when load currents (or temperatures, light levels, etc.) go outside of—or come within—preset limits. We'll look at some practical circuits in the next few pages.

Basic voltage comparator circuits

The easiest way to make a voltage comparator is to use an op-amp such as the CA3140; two basic configurations are shown in Fig. 1. The 3140 op-amp has a typical open-loop, low-frequency voltage gain of about 100 dB, so its output can be shifted from the high to the low state (or vice versa) by shifting the input voltage a mere 100 µV (microvolts) or so above or below the reference voltage value. The CA3140 can be powered from either a single-ended or split power supply and it provides an output that typically swings to within a couple of volts of its positive rail or to within a few millivolts of its negative (or zero) supply rail. Unlike many other op-amps, the 3140 can accept input voltages all the way down to the negative rail value.

The operation of the circuit in Fig. 1-a is very simple: A fixed reference-voltage (V_{REF}) is generated via the combination of R2 and Zener diode D1. It is applied directly to pin 3, the non-inverting input terminal of the op-amp. The input or test voltage V_{IN} is applied to the inverting input terminal (pin 2) via current-limiting resistor R1. When V_{IN} is below V_{REF} the op-amp output is driven high (to positive saturation), but when V_{IN} is above V_{REF} the output is driven low (to negative saturation). That response is shown graphically in Fig. 2-a.

By simply interchanging the connections to pins 2 and 3, the action of the circuit can be reversed; the op-amp output is normally low, but goes high when V_{IN} exceeds V_{REF}. That circuit is shown in Fig. 1-b, and its response is shown graphically in Fig. 2-b.

There are a few points worth noting about the basic single-supply voltage-comparator circuits in Fig 1. The first point is that the reference voltage can be given any value from zero up to within 2 volts of the positive supply-rail. Thus, either circuit can be made to trigger at any desired value between those limits by simply interposing a potentiometer between a fixed voltage-reference source and the "V_{REF}" pin of the op-amp.

The second point to note is that the voltage-input pin of the op-amp must be constrained to the range from zero volts up to within 2 volts below the positive supply-rail value. Thus, if you want the

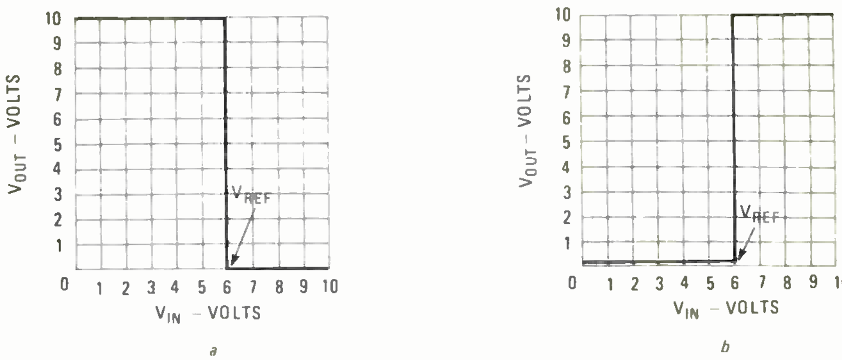

FIG. 2—THE ACTION OF THE VOLTAGE comparators shown in Fig. 1 is shown graphically here.

circuit to trigger at some high value of input voltage, you will have to feed the input voltage to a simple voltage divider before the op-amp input.

The final point to note about the basic voltage-comparator circuits is that they give a non-regenerative switching action, so that the op-amp is driven into the linear (non-saturated) mode when the input voltage is within a few tens of microvolts of V_{REF}. Under that circumstance, the op-amp output generates lots of spurious noise and that output will vary with slowly varying input signals. In some applications, that may be unacceptable. The problem can be overcome by using positive feedback, so that a regenerative switching action is obtained. The feedback signal introduces a degree of hysteresis in the voltage switching levels; the degree of hysteresis is directly proportional to the amount of feedback.

Special voltage-comparator circuits

Figures 3 to 7 show how the three points mentioned above can be put to practical use to make various types of "special"

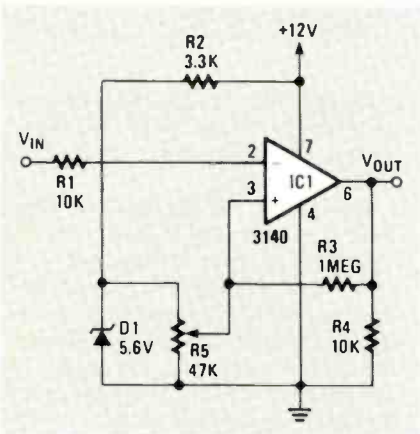

FIG. 3—THIS UNDER-VOLTAGE SWITCH lets you vary the V_{REF} trip point and offers regenerative feedback.

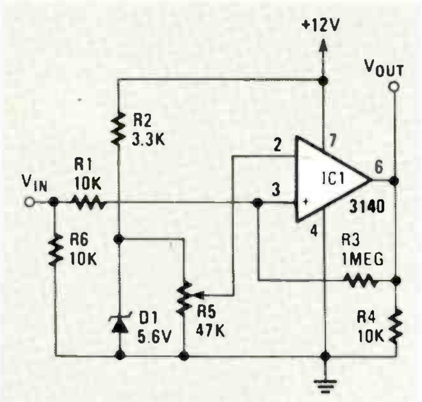

FIG. 4—THIS OVER-VOLTAGE SWITCH also offers regenerative feedback and adjustment of V_{REF}

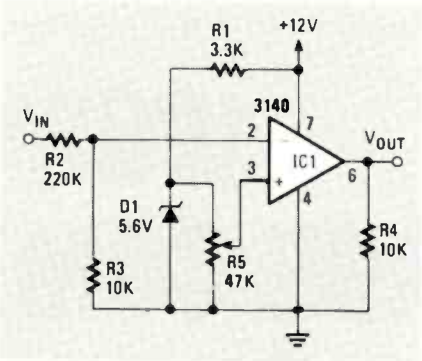

FIG. 5—A VOLTAGE DIVIDER allows us to use the voltage comparator to give high-value, variable-voltage triggering. This circuit does not offer regenerative switching.

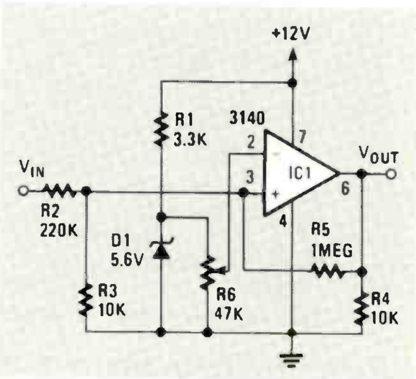

FIG. 6—THIS CIRCUIT, like that in Fig. 5, gives us high-value, variable-voltage switching. It offers regenerative switching.

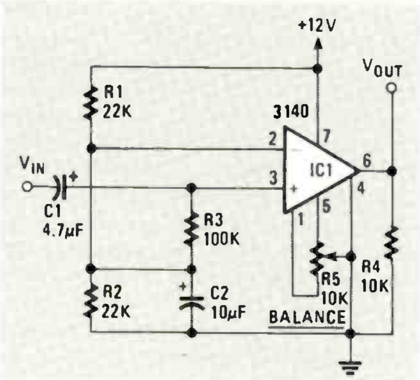

FIG. 7—THIS SINEWAVE-TO-SQUAREWAVE converter needs an input of under 100 mV to provide a 10-volt P-P squarewave output. The circuit can be used to about 15 kHz.

voltage-comparator circuits; plenty of other variations are possible. For example, Figs. 3 and 4 show how the basic comparator circuits can be modified so that the switching voltage can be varied by using a potentiometer (R5) to set the desired reference or trigger voltage at any value in the range 0–5.6 volts and to give regenerative (noiseless, snap-action) switching by feeding part of the op-amp output back to the non-inverting-terminal via R3. Note that in Fig. 4, the circuit's input terminal is terminated via R6 to ensure controlled hysteresis.

Figures 5 and 6 show examples of how the circuits can be modified to give high-value, variable-voltage (0–150 volt) triggering by interposing a simple voltage divider (R2 and R3) between the input signal and the input of the op-amp: The circuit in Fig. 5 gives non-regenerative switching, while that in Fig. 6 gives regenerative switching.

Figure 7 shows how the comparator can be used as a sensitive audio converter that converts sinewaves to squarewaves. It can operate from input-signal amplitudes as low as 10 mV peak-to-peak at 1 kHz and can produce decent squarewave outputs from sinewave inputs with frequencies up to about 15 kHz. The converter's input impedance is 100K. The operation of the circuit is rather simple: The voltage divider made up of R1 and R2, and capacitor C2 apply a decoupled reference voltage to pin 2 of the op-amp and an almost identical voltage is applied to signal-input pin 3 via isolating resistor R3. When a sinewave is fed to pin 3 via C1, it swings pin 3 about the pin-2 reference level, causing the op-amp output to transition at the "zero voltage difference" cross-over points of the input waveform and produce a squarewave output. Potentiometer R5 is used to bias the op-amp so that its output is just pulled low with zero input signal applied (so that the circuit operates with maximum sensitivity and stability). Because of the gain-bandwidth product characteristics of the op-amp, circuit sensitivity decreases as input frequency increases.

Window comparators

The voltage-comparator circuits that we have looked at so far give an output transition when the inputs go above or below a single reference-voltage value. It's a fairly simple matter to interconnect a pair of voltage comparators so that an output transition is obtained when the inputs fall between, or go outside of, a *pair* of reference-voltage levels. Figure 8-a shows the basic configuration, which is known as a window comparator.

The action of the circuit is such that the output of the upper op-amp goes high when V_{IN} exceeds the 6-volt V_U (upper limit) reference value, and the output of the lower op-amp goes high when V_{IN} falls below the 4-volt V_L (lower limit) reference value. By feeding the outputs of the two op-amps to R4 via the D1-D2 diode OR gate, we get the situation where the final output is low when V_{IN} is within the limits set by V_U and V_L, but goes high when the input is outside those limits.

By taking the output via a simple inverter stage, the action of the circuit in Fig. 8-a can be reversed so that its output goes high only when the input voltage is within the "window" limits. Alternatively, the required action can be obtained by transposing the two reference voltages and taking the output via a diode AND gate, as shown in Fig. 8-b. The actions of the two circuits shown in Fig. 8 are shown graphically in Figs. 9-a and 9-b.

Window comparators can readily be made to activate from any parameter that can be turned into an analog voltage, in the same way as a "normal" voltage comparator can. Let's look at some examples.

Analog-activated comparators

Figure 10 shows how a comparator circuit can be made to function as an over-current switch that gives a high output when the load current exceeds a certain value—which you can choose via potentiometer R6. The value of R_X is chosen so that it drops roughly 100 millivolts at the required trip point. Thus, a fixed reference voltage of 1/2 the supply voltage is fed to pin 3 of the op-amp via the voltage divider made up of R3 and R4. A similar but current-dependent voltage is fed to pin 2 via R_X, R1, R6, and R2. In effect, those two sets of components are configured as a Wheatstone bridge—with one side feeding pin 3 and the other side feeding pin 2—and the op-amp is used as a bridge-balance detector. Consequently, the trip points of the circuit are not significantly influenced by supply-voltage variations but are highly sensitive to load-current variations.

By simply transposing the connections to pins 2 and 3, the action of the circuit in Fig. 10 can be reversed so that it functions as an *under-current* switch: The circuit can then be used as a lamp- or load-failure indicator in cars, test gear, etc.

Figure 11 shows the circuit of a sensitive AC over-voltage switch that gives a high output when the input signal exceeds a peak value (6 mV to 111 mV) that is preset via potentiometer R12. The AC input signal is applied to the non-inverting input of variable-gain amplifier IC1. Its gain can be varied from 45 to 850 via R12. Note that the input of IC1 is DC-grounded via R1-R2, so the op-amp responds only to the positive half-cycles of the input signal. Consequently, the output of IC1 is an amplified, half-wave-rectified version of the input signal. That rectified signal is peak-detected via R5, D1, C2, R6, and R7, and is fed to the input of non-inverting voltage comparator IC2. The circuit's output is positive when the voltage across C2 exceeds the value on the junction of R8-R9.

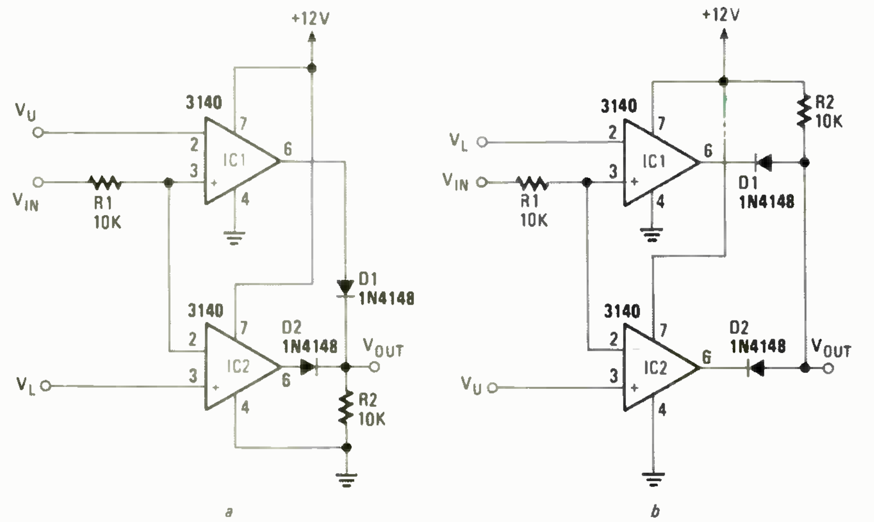

FIG. 8—TWO WINDOW COMPARATORS. When V_{IN} is outside the window determined by V_U and V_L; the output of the circuit in *a* goes high while the output of the circuit in *b* goes low.

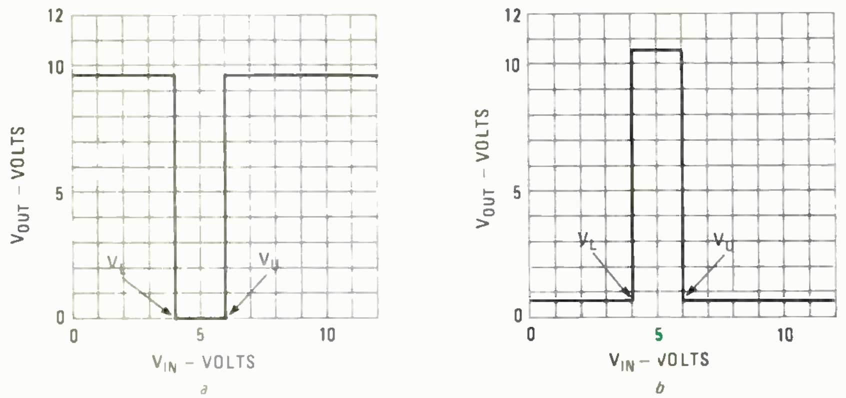

FIG. 9—THE ACTION OF THE WINDOW COMPARATORS shown in Fig. 8-a and 8-b are shown here in *a* and *b* respectively.

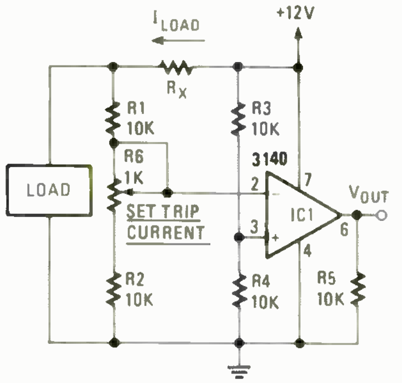

FIG. 10—OVER-CURRENT SWITCH. The output goes high when the load current exceeds a value determined by the setting of R6. By reversing the connections to pins 2 and 3 of IC1, the output will go low to signal the over-current condition.

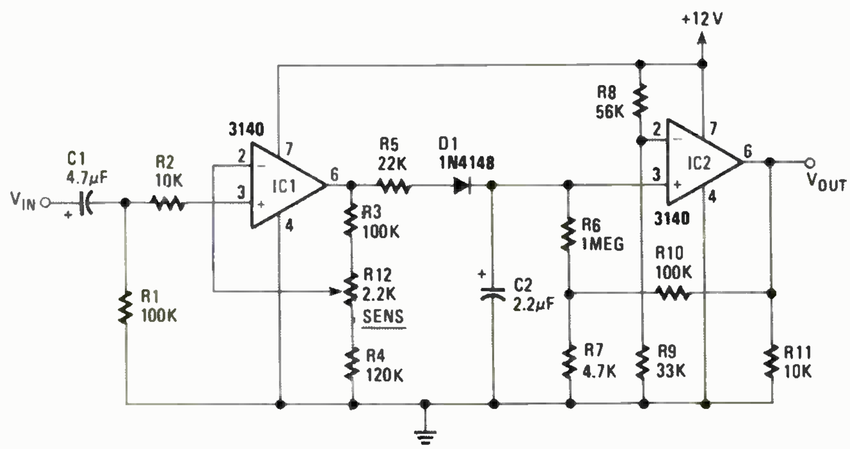

FIG. 11—AC OVER-VOLTAGE SWITCH can be triggered by input signals in the range of 6 mV to 111 mV peak.

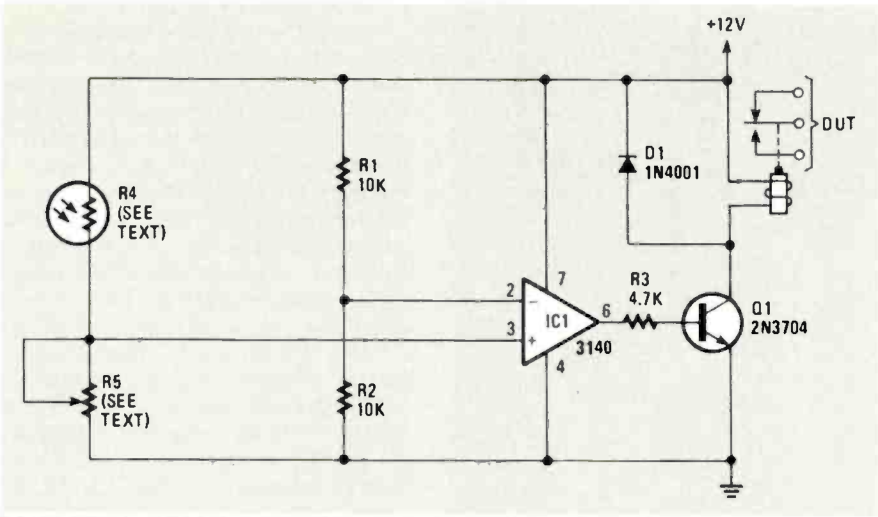

FIG. 12—THIS PRECISION OVER-TEMPERATURE SWITCH will control a relay.

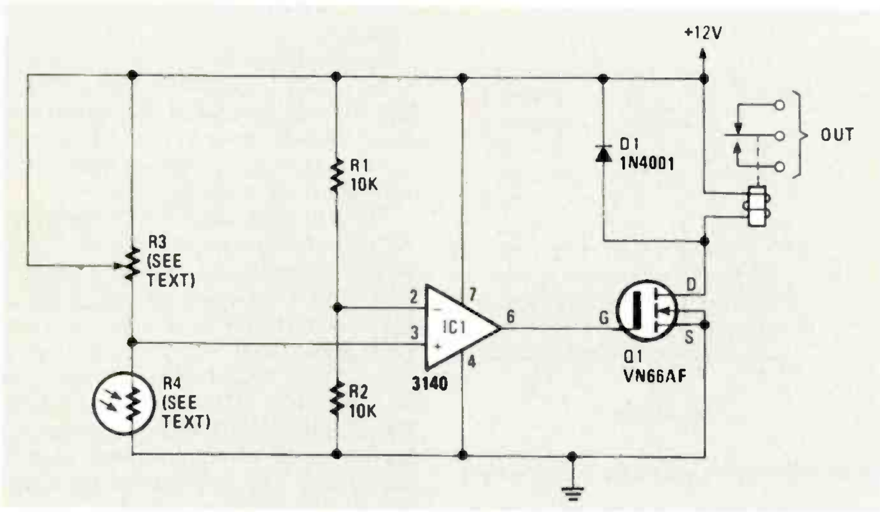

FIG. 13—THIS UNDER-TEMPERATURE SWITCH also will control a relay.

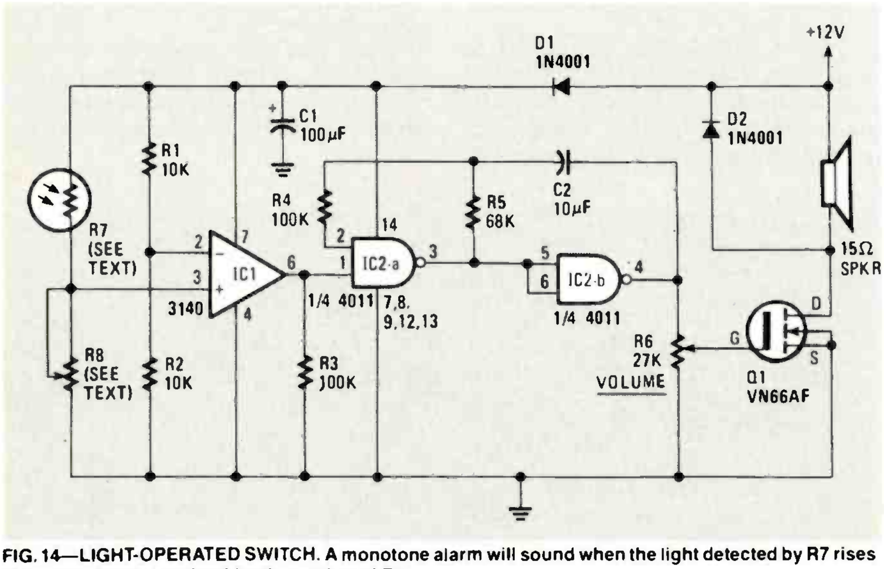

FIG. 14—LIGHT-OPERATED SWITCH. A monotone alarm will sound when the light detected by R7 rises above a value determined by the setting of R8.

Figures 12 to 15 show a variety of ways you can use comparator circuits as light- or temperature-activated switches. For light-sensitive circuits we use a cadmium-sulfide photocell; for temperature-sensitive circuits, we use an NTC (*N*egative-*T*emperature-*C*oefficient) thermistor as the sensing element. The sensing element is used as one arm of a Wheatstone bridge and the op-amp is used as a simple bridge-balance detector. Thus, the trip point of each circuit is independent of supply-voltage variations. In all cases, the sensing element must have a resistance in the range 5K to 100K at the required trip point. The potentiometer is chosen to have the same resistance value as the sensing element at the required trip level.

The circuits shown in Figs. 12–15 also show a variety of ways we can use the output of the op-amp to activate a relay or to generate an acoustic alarm signal. Thus, the over-temperature switch in Fig. 12 has a transistor-driven relay output, while the under-temperature switch in Fig. 13 has a FET-driven relay output. Similarly, the light-operated switch circuit of Fig. 14 generates a monotone alarm output signal in a small speaker, while the dark-operated switch of Fig. 15 generates a low-power pulsed-tone signal in a small acoustic transducer.

Micro-power operation

All of the 3140-based comparator circuits that we have looked at so far are continuously powered; they draw continuous currents of about 4 mA per op-amp. So if you wanted to use a 9-volt battery as a power supply, you'd find it running down after a couple of days of continuous operation. As you can see, the circuits that we've shown you so far are not well suited to battery operation in portable applications. In practice, however, all of those circuits can easily be modified for long-life battery operation by using a micro-power "sampling" technique; the principle behind that technique can be explained very easily with a simple example, as follows.

The under-temperature switch shown in Fig. 13 monitors temperature continuously and draws about 5 mA of quiescent current (with the relay off). In reality, however, temperature is a slowly-varying parameter and thus does not need to be monitored continuously—it can be efficiently monitored by briefly inspecting or sampling it. We can sample it by connecting the supply power and looking at the op-amp output only once every second or so. If the sample periods are very brief (say 300 microseconds) relative to the sampling interval (1 second), the *mean* current consumption of the monitor can be reduced by a factor equal to the interval/period ratio (in this example, by a factor of 3300). Thus, by using the sampling technique, we can reduce the 5-mA consumption of circuit in Fig. 13 to a *mean* value of 1.6 µA.

Figure 16 shows the basic circuit of a "micro-power" or sampling version of the under-temperature switch we saw in Fig. 13. It operates the relay when the temperature of the thermistor falls below a preset value but it draws a mean quiescent

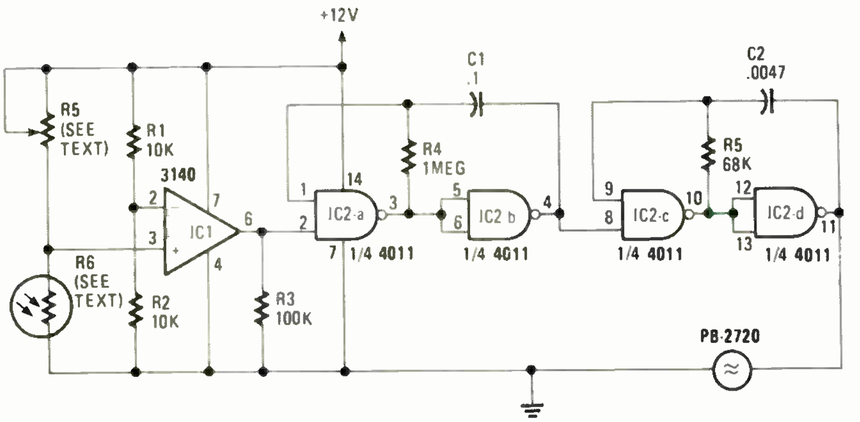

FIG. 15—ANOTHER LIGHT-OPERATED SWITCH. A pulsing tone will sound when the light detected by R6 falls below a value determined by the setting of R6.

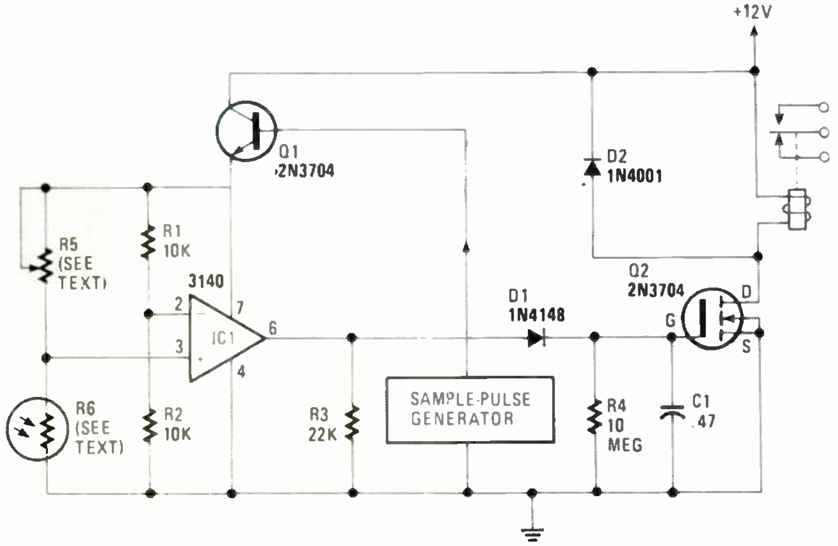

FIG. 16—MICRO-POWERED UNDER-TEMPERATURE SWITCH draws a quiescent current of only a few microamps.

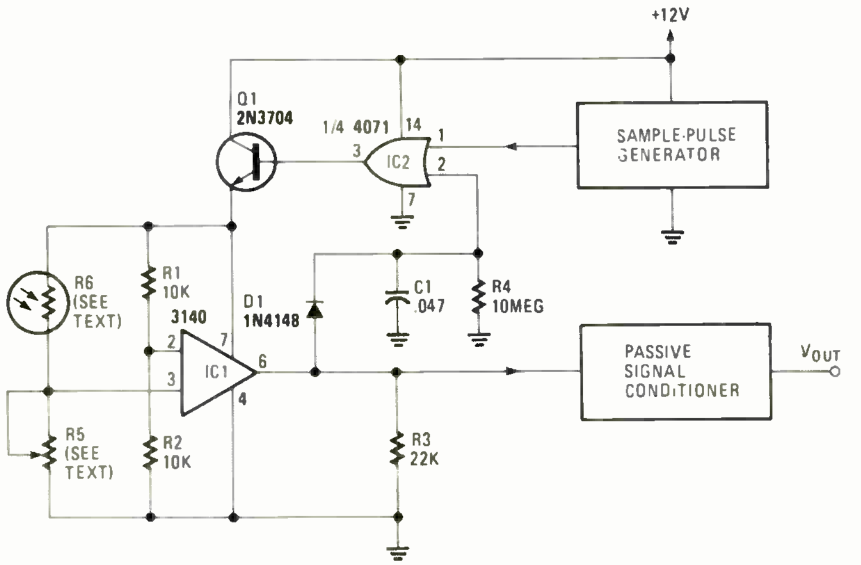

FIG. 17—THIS CODED-LIGHT-BEAM DETECTOR uses a modified version of the sampling technique to monitor for the presence of a coded light-signal.

current of only a few μA. The monitor network, made up of R5, R6, R1, R2, and IC1, is almost identical to that of Fig. 13. But instead of being continuously powered, it is powered via a 300-microsecond pulse just once every second via a sample-pulse generator and Q1. Note that the output of IC1 is fed to temporary "memory" store R4-C1 via D1, and that the memory store operates the relay via Q2.

Thus, if the thermistor temperature is outside the trip level when the sample pulse arrives, the output of IC1 will remain low and no charge will be fed to C1, so Q2 and the relay will be off. On the other hand, if the thermistor temperature is within the trip level when the sample pulse arrives, the output of IC1 will switch high for the duration of the pulse and thus rapidly charge C1 up via D1 and drive the relay on via Q2.

The circuit in Fig. 16 illustrates the basic principles of the micro-power sampling technique. In reality the sampling interval and pulse width used (and, thus, the reduction in mean power consumption) will depend on the specific application. If, for example, you wish to monitor transient changes in light or sound levels and know that these transients have minimum durations of 100 ms, you may have to use a 50-ms sampling interval and (say) a 500 μs sample pulse. In that case the mean consumption of your circuit will be reduced by a factor of 100.

In some cases, you may have to slightly modify the operating principle of the sampling circuitry to obtain the desired micro-power operation. Figure 17, for example, shows how the principle may be adapted to make a coded-light-beam detector, in which the "code" light signal is modulated at 1 kHz for a minimum duration of 100 ms. Thus, the sample-pulse generator is designed to produce a minimum pulse width of 1.2 ms so that it can capture at least one full 1-kHz code cycle. Further, the sampling interval is set at 60 ms so that part of a tone burst will always be captured. The sampling circuitry thus gives a 50:1 reduction in monitor-current consumption.

Thus, in the circuit shown in Fig. 17, the sample generator repeatedly feeds 1.2 ms "inspection" pulses to the 3140 detector circuitry via one input of the OR gate and via Q1 to see if any trace of a coded signal exists: If no trace of a coded signal is detected, the output of the op-amp remains low and another sample pulse is applied 60 ms later. If a trace of a code signal *is* detected, the output of the op-amp switches high and the resulting pulse is "captured" and applied to the remaining input of the OR gate. That temporarily applies full power to the 3140 circuitry so that the code signal can be completely inspected via the passive signal conditioning circuitry. **R-E**

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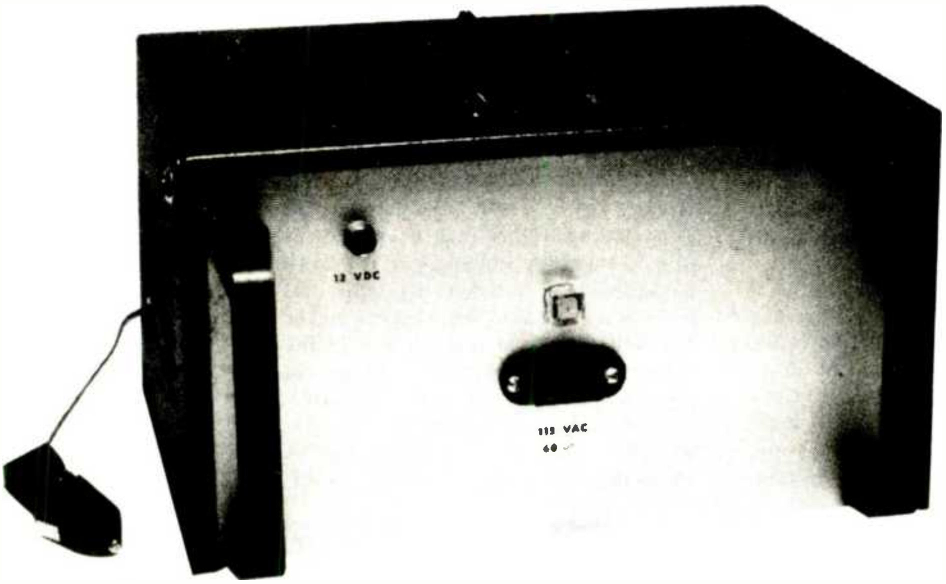

Did you ever wish you could have a backup AC power supply in case of a power failure? Or did you ever wish you could take one or more of your home appliances with you on family outings? Well, this easy-to-build power inverter can help you do both!

DAVE SWEENEY

A POWER INVERTER IS USEFUL GADGET that can lend some degree of portability to otherwise home-bound electronics devices. Its function is to convert a low DC-voltage to a usable AC level. The power inverter we'll describe here will let you generate alternating current that will allow you to power a small television, personal computer, strobe light, or other AC-operated device without being tied down to an AC outlet.

While the project was originally designed so that AC devices could be operated in a car (from the 12-volt system), it has another important use: it can serve as part of an uninterruptable (backup) AC supply. If you suffer from some short-term power outages, it could be particularly valuable. Your burgular alarm could still operate during a blackout, and your clock would still keep time.

We won't go into detail on particular applications of the uninterruptable power supply. But we will mention that you have several options for making the unit "kick in" automatically when the power company cannot deliver. The easiest way, as shown in Fig. 1, is to use a 117-volt relay to switch between the standard AC line or the 117 volts from the inverter. One possible disadvantage there is that the relay might not be fast enough in some applications. For example, only a very slight disruption in power can overwrite your computer's memory with garbage. Only experimentation will let you know for sure. A solid-state relay, which typically has a faster switching time than a mechanical relay, might be your best bet. In either case, you'll want to make sure that you have a fully charged battery to supply power to your inverter. A trickle charger would be a valuable addition to the circuit.

Provided the inverter's power capacity is not exceeded, you can power most any AC-operated device indoors or outdoors, and during power failures. Be cautioned however, that the output of this inverter is closer to a squarewave than a sinewave. Even though the high-frequency components of the squarewave output are filtered, some devices will not operate properly with such an input and others may even be damaged!

In a motor vehicle (which is where this unit was designed to be used), the inverter produces 117-volt AC from your auto's 12-volt DC battery. So you can use the unit to add to the fun of an outdoor party, or even to power an electric razor while you wait in line at the drive-in bank!

Voltage isn't everything

Besides generating the correct AC voltage, an inverter must provide the correct frequency. Many devices, especially those with transformers or motors, require 60 Hz. If the frequency varies as the load changes, or when the DC input fluctuates, the performance of the device may be reduced, or the equipment might be damaged.

Low-power, inexpensive inverters typically rely on a special winding of the transformer for oscillation. Since most inverters are little more than an oscillator with specially wound transformers, the unit's output frequency is determined by transformer's inductance. Therefore, loading the transformer changes its effec-

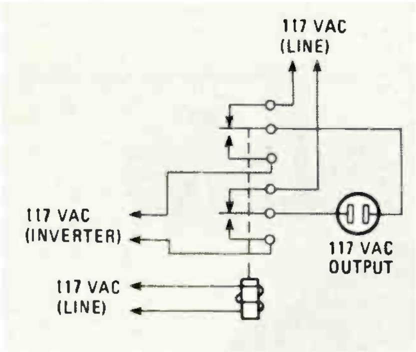

FIG. 1—A SIMPLE RELAY SETUP will let you use the inverter as a backup power supply.

tive inductance, and results in an output-frequency that varies with load requirements.

The inverter power supply that we'll describe here overcomes that deficiency by using a 555 oscillator to control the output frequency. Isolated from the power output, the oscillator maintains a 60-Hz output frequency regardless of the load. And if that isn't enough, it has a low parts-count and the parts used are easy to find. For example, the transformer is an inexpensive, general-purpose 25.2-volt center-tapped, 2-amp unit with a single high-voltage winding.

Circuit description

Figure 2 shows a schematic of the power supply inverter. MOSFET transistors, Q3 and Q4, form a flip-flop whose output is used to turn power transistors Q1 and Q2 on and off alternately. When Q1 is on, current flows in half the low-voltage winding; when Q1 is off, Q2 is on and current flows in the other half of the low-voltage winding.

Transformer T1, which has a 117-volt primary and 25.2-volt secondary is used as a step-up, rather than a step-down, transformer. (A transformer transfers power in either direction—the terms *primary* and *secondary* are assigned rather arbitrarily.) Current in each half of the center-tapped winding flows in opposite directions (i.e., positive and negative). That alternating current (AC) in the center-tapped "secondary" winding induces AC in the high-voltage "primary" winding. That voltage step-up results from the operation of Q1 and Q2, which are turned on and off alternately.

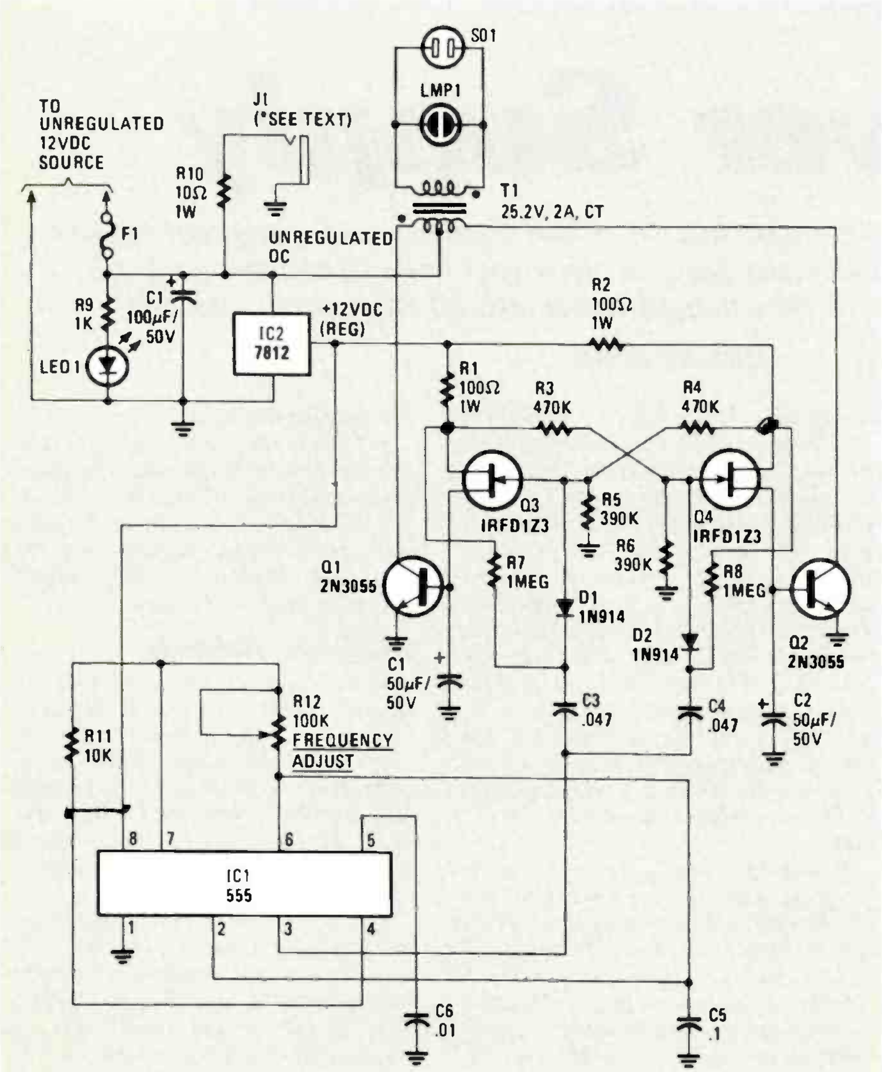

FIG. 2—THE INVERTER SCHEMATIC. Note that the transformer's center tapped secondary is connected as the input. So T1 is used as a step-up transformer.

As long as the power transistors (Q1 and Q2) alternate at 60 Hz, the output voltage will also be at 60 Hz. To maintain that operating frequency, the flip-flop (Q3 and Q4) switches the base currents of Q1 and Q2. The flip-flop is triggered by the output of the 555 oscillator, IC1. Since Q3 and Q4 conduct alternately, they are always inversely related to each other. And because they operate from the same trigger, they'll always generate a symmetrical AC squarewave.

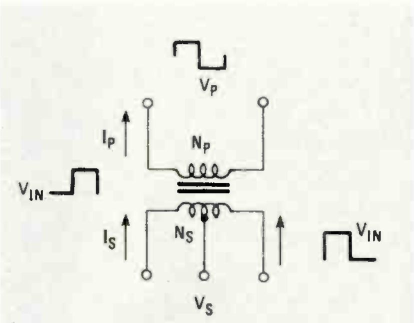

FIG. 3—WHEN A 60-Hz AC VOLTAGE is applied to a standard transformer, the relationships of the voltage (V), current (I) and windings (n) may be expressed as $V_P/V_S = I_S/I_P = N_P/N_S$.

Now let's turn to Fig. 3 for a discussion of the turns ratio and transfer characteristics of the transformer. When a 60-Hz AC voltage is applied to a standard transformer, the relationships of the input/output voltage (V), current (I), and the number of turns in the transformer windings (N) can be expressed as $V_P/V_S = I_S/I_P = N_P/N_S$. For the transformer specified, the turns ratio is 117/25.2; therefore, feeding 25.2-volts AC to the secondary of T1 (without allowing for inefficiencies) produces a 117-volt output.

Since transformer T1 is rated at 2-amperes maximum in the secondary winding, the transferable power is 25.2 (V) × 2 (A) or 50.4 watts. Because the turns ratio determines the output voltage, applying 12-volts AC to half the secondary also yields an output of 117 volts. However, the output power capacity will be cut in half.

To increase the capacity of the unit, connect two identical transformers in parallel, a similar effect to placing two batteries in parallel. Just be sure to connect like terminals together, so as not to cause a phase difference that could damage the transformers! The unit's power-handling capacity will then be then the sum of all parallel transformers.

The net result is while transformer T1 determines the step-up voltage level, the 555 oscillator determines the output frequency. Therefore, even if T1 is severely loaded, the oscillator and MOSFET's maintain a symmetrical 60-Hz AC signal for T1.

PARTS LIST

All resistors ¼, 5% unless otherwise noted.
R1, R2—100 ohms, 1 watt
R3, R4—470,000 ohms
R5, R6—390,000 ohms
R7, R8—1 megohm
R9—1000 ohms
R10—10 ohms 1 watt
R11—10,000 ohms
R12—100,000 ohm potentiometer
Capacitors
C1, C2—50µF, 50 volts electrolytic
C3, C4—.047µF, ceramic disc
C5—.1µF, ceramic disc
C6—.01µF, ceramic disc
C7—100µF, 50 volts electrolytic
Semiconductors
IC1—555 oscillator
IC2—7812 12-volt regulator
Q1, Q2—2N3055 NPN power transistor
Q3, Q4—IRFD1Z3 N-channel FET
D1, D2—1N914
LED1—Standard red LED
LMP1—neon panel lamp
T1—25.2 volts, 2A center-tapped
Miscellaneous: Cabinet, perforated construction board, AC panel socket, miniature phono jack, 4A slow-blow fuse, cigarette lighter plug, etc.

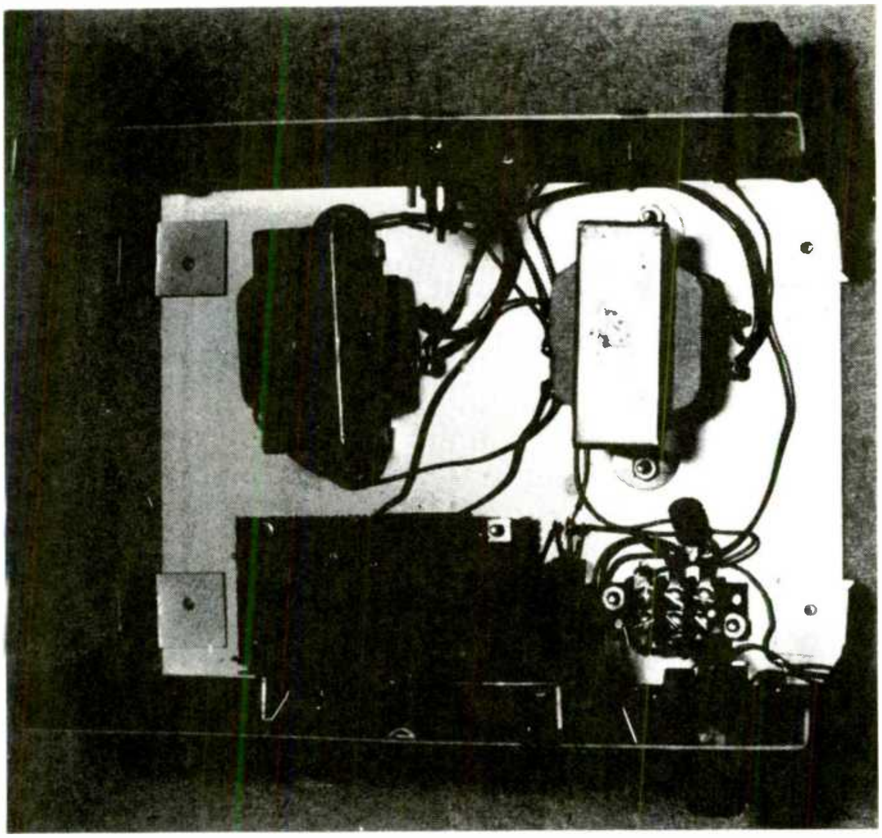

FIG. 5—THE AUTHOR'S PROTOTYPE is shown here installed in metal cabinet. Note that two transformers are used to increase power handling capabilities.

Circuit operation

Capacitor C5 and potentiometer R12 determine the frequency of the output signal at pin 3 of IC1, the 555 oscillator. The output signal is differentiated by C3 and C4 before it's input to the base of the two power transistors (Q1 and Q2) via diodes D1 and D2, respectively. The signal from IC1 is adjusted to 120 Hz. That's because the flip-flop formed by transistors Q3 and Q4 divides the frequency by 2.

When Q3 is on, the base of Q1 is connected via R1 to the regulated 12-volt supply. Then, when the flip-flop changes states, Q4 is turned on and the base of Q2 connected to the 12 volt supply through R2. The 100 mA base current allows Q1 and Q2 to alternately conduct through their respective halves the transformer's secondary winding

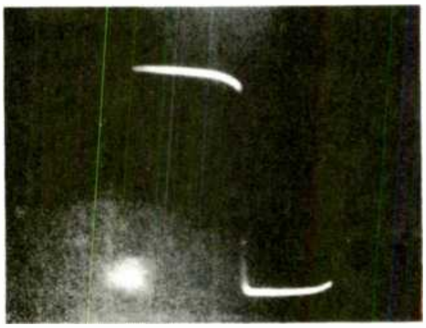

FIG. 4—THE ABOVE TRACE SHOWS the 60-Hz output from the inverter. Note that although the output is closer to a squarewave than a sinewave, most of the high-frequency components have been removed.

To eliminate switching transients caused by the rapid switching of Q3 and Q4, capacitors C1 and C2 filter the inputs to the base of Q1 and Q2 respectively. Figure 4 shows the waveform that appears at the output (primary) of the transformer. Though the output is not a sinewave, it is close enough to operate all but the most critical equipment. But don't risk damage to your expensive equipment if you're not sure. As a rule of thumb, if your equipment can be damaged by transients, it's not a good candidate for this backup power supply.

Power for the unit comes from your automobile's 12-volt system, or—if you want to use the inverter for backup applications—from a storage battery. It is regulated by IC2 (a 7812 regulator). LED 1, connected across the 12-volt input, may be used to indicate whether power is being fed to the circuit. The neon pilot lamp, LMP 1, shows a presence or absence of output power. Jack J1 is included to provide a convenient 9-volt DC supply for a videogame, like the Atari *2600*.

Circuit construction

The method of construction is not critical, but if you're going to build the inverter as a portable unit, it's important to build it to withstand punishment. The author's prototype was built on perforated construction-board using point-to-point wiring, as shown in Fig. 5. Note that there are two transformers shown; as mentioned previously, two or more transformers may be paralleled to increase the unit's power handling capacity.

The power-inverter circuit should be housed in a metal cabinet, and power transistors Q1 and Q2 should be heat sinked. To avoid damage from vibration, the components should be secured to the driver board with an epoxy adhesive.

The FREQUENCY-ADJUST potentiometer, R12, should be set prior to connecting the collectors of Q1 and Q2 to the transformer. Set the frequency at pin 3 of the IC1 to 120 Hz; then using a scope, monitor the base of both Q1 and Q2 to verify that a 60-Hz signal is present. Once the signal is established, the Q1 and Q2 collectors may be connected to the transformer.

Potentiometer R12 may be mounted on the panel to allow frequency adjustments from outside the inverter. To test the unit out, plug it into the cigarette-lighter socket in the vehicle. Both pilot lights should come on. If not, go back and check your work. If all is well, the unit is ready for use.

Safety procedures

Caution: Keep in mind that the inverter, whether being tested or used, has the same output-voltage level as that of an ordinary household power-outlet and is just as dangerous. Exercise the same caution that you would in dealing with household line voltage. R-E

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BENCH POWER SUPPLY

Continued from page 115

−40 volts across D2 and D4, and +20 volts across C11 and C12. While you're at it, verify the presence of +20 volts on pin 7, and −20 volts at pin 4 of each op-amp. If everything checks out, remove power and insert the IC's. Be sure to orient pin 1 correctly.

Run wires from the transistors mounted on the rear panel (see Fig. 7) to the PC board. Finally, using Fig. 6, complete the point-to-point wiring between the board and the front- and rear-panel components. At this point, your power supply should appear similar to the prototype shown in Fig. 8.

Calibration

A DMM or VOM accurate to at least 4½ digits should be used to calibrate the precision sources. To obtain sufficient resolution, allow the supply to run for 10 minutes or more so that the temperature within the cabinet—and the output voltages of the precision sources—will stabilize. Adjust R44 and R51 so that their dials read 10.00 (i.e., their resistance should be exactly 10K ohms). Then adjust trimmer potentiometers R43 and R50 so that each output reads exactly 10.000 volts.

To get symmetrical outputs from the independent supplies, adjust R11 so that equal rotation of potentiometers R6 and R15 gives the same output voltage.

To adjust the dual-tracking source, turn potentiometer R24 to maximum resistance. Then adjust R29 for an output of exactly +15.000 volts, as measured at the $+V_T$ output. Then adjust R32 so that exactly −15.000 volts appears at the $-V_T$ output.

Substituting components

Some of the components specified in the Parts List may be difficult—if not impossible—to find. For example, you may have that problem with the 40-volt Zener diodes (D2 and D4). However, two 20-volt Zener diodes may be connected in series to achieve the same result.

The 2.7-volt Zener diodes (D8 and D10) may also be difficult to find. If they are, 3.3-volt units may be substituted (1N5226B). If doing so produces more than 1 mA from the constant-current sources, trimmer potentiometers R43 and R50 can be adjusted to compensate. The 6.8-volt reference diodes (D5 and D6) are not critical and may be either 1N957B, 1N5235B, or 1N4736A devices. The two 12-volt Zener diodes may be 1N963, 1N5242B, or 1N4742A units.

All electrolytic capacitors are polarized aluminum types, and radial-lead devices were used in the prototype to conserve space on the PC board.

All five cermet trimmer potentiometers used in the project are the ¾-inch long rectangular type.

Increasing power output

If you want to beef up the outputs of the non-precision supplies, you must increase the current capacity of the transformer, the output transistors, etc.

The transformer specified for this project has a rated output of 40-volts center-tapped at 300-ma. You may replace it with a unit having higher current capacity, but if you use a transformer with a higher voltage rating, be careful not to exceed the voltage rating of the op-amps and transistors.

The 2N3766 transistors (Q1 and Q5) may be replaced by 2N6057 devices; the latter have a maximum collector current of 12 amps. The 2N3740 transistors (Q3 and Q7) may be replaced by 2N6050 units, which also have a maximum of 12 amps. Both the 2N6050 and 2N6057 are housed in TO-3 cases and will require additional heat-sinking.

If you are using the metering circuit, the value of R52 might have to be increased, as well as the the rating of the current meter. **R-E**

CRYSTAL RADIO

Continued from page 118

tinuity from the beginning of the coil to the end.

The coupling coil, L2, is wound in the same manner as the larger coils, but it's wound on a smaller (3¾-inch diameter) form, and is made up of 16 turns of 26-gauge DCC wire. The anchor spoke has a single mounting point, so that the coupling to L3 can be adjusting by pivoting L2 around that point.

Diode D1 can be just about any germanium diode. But if you want to keep your crystal radio authentic-looking, you should mount it in a case like the one shown in Fig 2. Such cases were commonly used to mount fixed-contact cat-whisker detectors.

The variable capacitor is a 200-pF device. It won't be easy to find, so feel free to experiment with its value. Capacitors C1 and C3 are fixed-mica types.

Perhaps the most important part of building the receiver is putting up the antenna system. For good results, your antenna should be as long and as high as possible. If you can manage to put up a 75-foot long-wire antenna, great! Just remember: your ground system is also very important. A four-foot copper pipe or rod hammered into the earth can make a good ground. If you can't manage that, try your cold-water pipe.

The wooden base shown in the photographs is about 11 by 7 inches (it's ¾ inch thick). The edges are routed for a smooth appearance. Choose some type of hardwood, such as oak or maple for the base, and sand it well. Stain it according to taste, and then give it a couple of coats of satin-finish polyurethane. *(Sand very lightly)* between coats.

If you want to finish both sides of the breadboard base at the same time, then use four woodscrews as temporary feet. (Install them where you will be installing the rubber feet.) Finish the bottom of the breadboard first, and then turn it over and finish the top and the sides. The screws will keep the bottom of the board from touching anything else. Before you give the breadboard a second coat (which we do recommend), just be sure to let the first coat dry thoroughly. Then sand very lightly with super-fine-grit paper, and apply the second coat.

When your base is finished, it's time to start mounting parts. The parts on the prototype (and the available kit), including the coil taps, are mounted on small bakelite panels which are, in turn, mounted to the base. The main tuning capacitor, the headphone jack, and the antenna tap switch are mounted to the front panel, which is, in turn, mounted to the base using small "L" brackets.

Operating the receiver

Tuning your crystal set can be tricky business until you get used to it. The first step is to set the detector tap to the midway point, and to set the antenna tap switch, S1, to 0 (minimum inductance) and adjust L2 for maximum coupling to L3. When you plug in your high-impedance headphones, you'll hear one or more stations.

Tune to a station at the lower-frequency end of the band by adjusting the main tuning capacitor, C2, so that its plates are about 2/3 in mesh. Then reduce the coupling between L2 and L3, until you can barely hear the station. Advance the antenna tap switch until you reach the peak volume for that station. When that station is tuned, you can reduce the coupling further between L2 and L3. While that will reduce the volume, it will increase the receiver's selectivity, so you can tune in other stations on nearby frequencies.

Once you get used to tuning the radio, you can experiment with the detector tap. If you are in a strong-signal area, you can probably get by with decreased inductance of L3. That will increase the receiver's selectivity also. **R-E**

RADAR CONTROLLER

continued from page 58

Once you've etched or purchased the board, mount the components on the board as shown in the parts-placement diagram, Fig. 7. Be sure that all components are oriented as shown. Bolt the regulator and power the transistor to the circuit board for heat sinking.

The Gunn diode, which is mounted in a microwave horn, draws up to 1 amp of current, so use number 18 wire for the connection between the circuit and the horn, and keep the length to 10 feet or less. *Under no circumstances* should you connect DC voltage to the Gunn diode or reverse the polarity of the connections to the diode (power is fed to the anode side; the cathode side is grounded). Doing either will almost certainly blow out that $60.00 component.

When mounting the microwave horn, be sure that metal objects are kept away from the opening (plastic will do no harm). The power supply for the unit should be able to supply 12-volts DC at 2 amps; most automotive electrical systems are capable of meeting that requirement.

After construction and hook-up, test the unit by aiming it toward an automotive radar detector and depressing the TRANSMIT switch. That should cause LED2 to light. Also, the radar detector should react as appropriate (a buzzer should sound or an LED should flash) to the presence of a radar signal. Verify the oscillating frequency of the 555 timer by connecting a scope or frequency counter to pin 3 of that IC. With the S3 set to 55, the frequency measured should be 39,600 Hz.

Warnings

While the radar calibrator can be a useful diagnostic tool in aligning radar speed-guns, if used for illegal purposes and/or by unlicensed individuals, it can be the cause of a great deal of trouble. (Penalties of up to $10,000 and a year in jail are some of the possible consequences of such use.) Further, because of possible interference to police radar, communications services, etc., the unit should only be used in a laboratory, and only for educational or calibration purposes.

It may be possible for certain individuals, such as licensed amateur-radio operators, to use the calibrator legally in the workshop, the laboratory, or the field, but it is left to the individual user to ascertain the requirements for such use, and to meet them.

In any event, any willful interference to another service by any individual is punishable with stiff penalties under Federal law; other local, state, or Federal penalties may also be applicable. We strongly discourage use for such applications. **R-E**

POWER SWITCH

continued from page 62

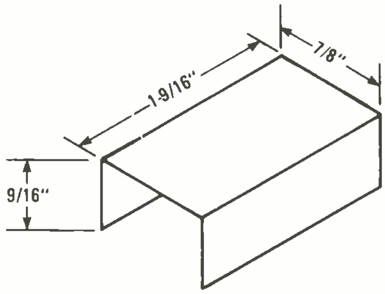


FIG. 7—CUT AND BEND THE UPPER SHIELD from a thin piece of tin as shown here.

until you get some response from the circuit. Don't worry about making an exact adjustment. The adjustment we're doing now is preliminary; the receiver must be fine-tuned to obtain maximum range of about 30 feet.

After you get a response, solder the shields in place. The easiest way to do that is to melt a small amount of solder in each corner of the shield. Then set the shield in place and heat each corner in turn to let the solder flow onto the pin.

To fine-tune the receiver, set it up in a position where you can get a clear line of sight to it for a distance of about 30 feet. Position yourself about five feet from the receiver, point the transmitter at the receiver, and press the TRANSMIT button.

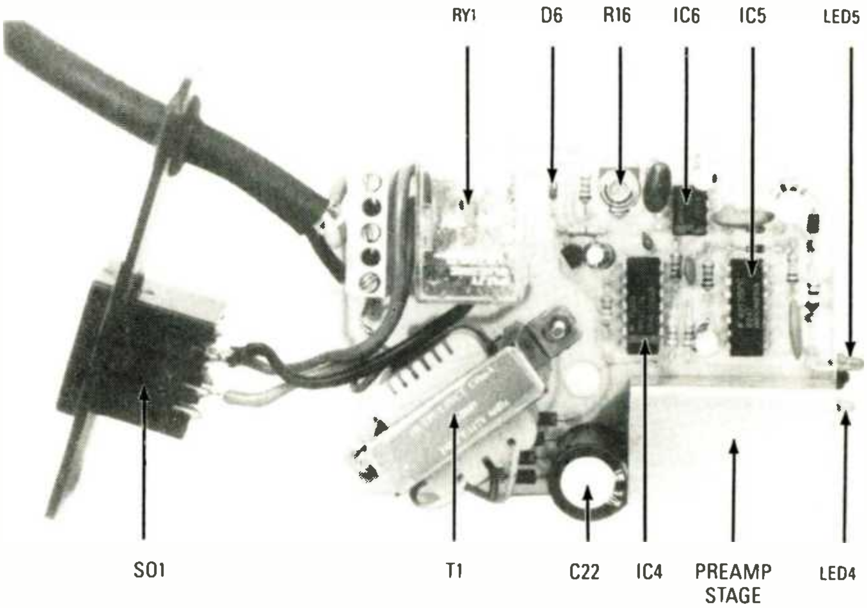


FIG. 8—THE RECEIVER'S PC BOARD should appear as shown here after all components have been mounted.

tal. Then fit the panel over the two LED's so that the legs of the filter fit around the photodiode. Insert the panel-board assembly into the bottom half of the receiver case.

Testing and alignment

Plug the receiver into an AC outlet. The SIGNAL LED should light briefly and then go out, and the ON LED should remain off. Set trimmer potentiometer R16 to the center of its range.

Now aim the transmitter at the photodiode and press S1. With a little luck, the center frequency of the 567 will be close enough to the transmitter's output frequency that the SIGNAL LED will light up temporarily. The ON LED should light up and stay lit, and the relay should latch on. A second press of the button will turn the LED and the relay off—that is, of course, only if you're lucky.

If the receiver doesn't respond, adjust R16 slightly and try again. Repeat that

If the receiver responds, back up another five feet and try again. Remember to let the transmitter recharge for a few seconds between transmissions, particularly when you're standing back at distances of ten feet or more.

Continue backing up in five-foot segments until you reach a point where the receiver will not respond. At that point, adjust R8 slightly and try again. An assistant to handle the transmitter would be helpful.

Even under worst-case conditions, the receiver should be able to respond when the transmitter is 20 feet away. If you can adjust it to respond to signals only up to a certain distance but no farther, your problem is likely due to overly bright lighting, electrical or RF noise, or something else. Don't blame the receiver!

Assemble the case and plug the device you want to control in. You're now free to operate that device at your convenience, free from the tyranny of its switch! **R-E**

STUNGUN

continued from page 121

board can be purchased from the source mentioned in the Parts List. If you build the circuit on a perfboard, follow our parts layout closely; otherwise you may have problems with arcing.

Due to the critical nature of the three transformers, we are not providing details on winding them. They are available from the source mentioned in the Parts List.

Referring to the parts-placement diagram in Fig. 2, and the photos in Fig. 3 and Fig. 4, mount all components except C2, T1, T2, and T3 on your board. Note that several components mount on the foil side of the PC board: C1, D7, and J1. Do not install those parts yet either.

After all components (except those mentioned above) are installed, check your work very carefully, especially D1–D6, R1, and R3, because T1 will be installed above them, and there will be no chance to correct errors later. After you're absolutely sure that they're installed correctly, install T1 with the black mark on the windings mounted toward C2.

Foil-side components

One of J1's tabs shares a hole on the PC board with resistor R8, which should be mounted already. Solder the tab of J1 that corresponds to the tip (not the barrel) of an inserted plug to the indicated pad. Then mount C1 and D7. Last, solder a 1¼-inch piece of 18-gauge wire to the barrel pin of J1, and connect the opposite end of that wire to the appropriate pad beneath S1, the FIRE switch.

Preliminary check-out

WARNING: While measuring voltages and currents, keep your face, hands, and all metallic objects away from the high-voltage end of the stun gun. If if you want to prod a component, use a non-conductive rod such as a plastic TV alignment tool. High voltage behaves very differently than low voltage. Any material that retains moisture can serve as a discharge path. THAT INCLUDES WOOD! Also, never work on or use the unit when your hands are wet.

Connect a voltmeter (set to a 1000-volt DC range) to ground and to the output of the D3–D6 diode bridge. Then power up the circuit using either a freshly-charged battery or an external supply capable of delivering 9.8 volts at one amp. If everything is working properly, you should measure about 400-volts DC at the output of the bridge when you press S1.

If you don't measure that voltage, connect an oscilloscope to the collector of Q1 or Q2. You should see a squarewave with a period of about 100 μs. If that waveform is not present, the switching circuit is not operating correctly. *Remove power* and check your wiring again. *Do not debug the circuit with a battery connected!*

Resistor R6 controls the rate at which the UJT (Q3) discharges, and R3 controls the rate at which C2 charges. You can experiment with the values of those components if you are not satisfied with the circuit's high-voltage output. R3 can vary from 2.2 to 4.7K. You can also experiment with the value of C2. See Table 1.

After the circuit is operating correctly, attach J1 to the board with high-voltage potting compound or RTV. And before you mount the circuit in a case, make sure there's no arcing on the PC board. If there is, you can stop it with a liberal application of RTV, paraffin, or epoxy.

Conclusion

The stun gun's discharge is very impressive. The spark is highly visible and each discharge produces a sharp, resounding crack. The circuit can teach you much about voltage-multiplying circuits and power supply design. But don't ever forget that the stun gun is not a toy. It can cause much damage to both you and others. Never leave it lying around where children, pets, or anyone unfamiliar with how to use it can handle it. It's a good idea to remove the battery before storing the stun gun. Above all: be careful! **R-E**

RADAR SIGNAL DETECTOR

continued from page 122

power, background noise should be heard. You may want to vary the value of R1 slightly to get a pleasant ringing frequency. Then adjust the threshold control (R5 in Fig. 1; R2 in Fig. 2) so that received signals are just above the $1/f$ noise background.

You can test the detector on the workbench by generating a millimeter-wave microwave signal. You don't need a fancy signal generator—just "arc" a small inductor (say 500 mH) across a nine-volt battery. A properly-functioning detector should ring loudly when a signal is generated in that manner fifty feet from the detector. You may want to experiment with different inductors at different distances from the detector.

Conclusions

Both circuits pick up low-level pulsed-RF signals. The detector responds to very short pulses and will continue to ring for several milliseconds. But the circuit will respond only to the beginning and the end of a CW (continuous-wave) signal. Using either circuit, you'll soon be able to recognize various signal sources by their "signatures." Microwave towers, for example, provide lots of varied output.

Either circuit could be used for purposes other than radar detection. For example, you could use one to detect a hidden radio transmitter (provided the transmitter is a pulsed type). The detector could be used as a leakage detector at a microwave tower. The detector could also be used to detect leakage or arcing in home power lines, as well as outdoor power-transmission lines. In fact, the uses to which this circuit may be put are limited only by your imagination! **R-E**

PARTS LIST—ECONOMY MODEL

All resistors ¼-watt, 5%.
R1—1.1 megohm
R2—27,000 ohms
R3, R4—100,000 ohms
R5—100,000 ohms, panel-mount potentiometer

Capacitors
C1—0.22 μF
C2—0.0 μF
C3—100 μF, 16 volts, electrolytic

Semiconductors
IC1—1458 dual op-amp

Other components
S1—SPST switch
Piezo-electric transducer

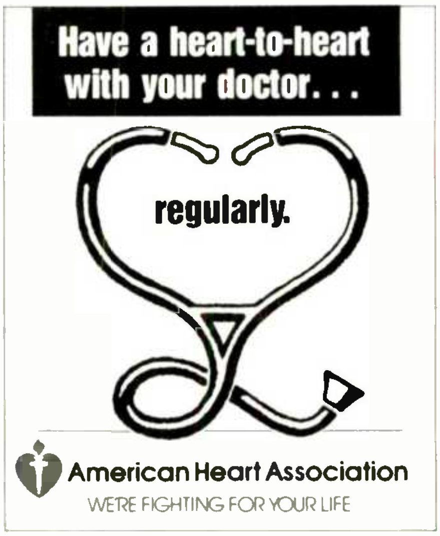
PARTS LIST—DELUXE MODEL

All resistors ¼-watt, 5%.
R1—2.2 megohms
R2—10,000 ohms, trimmer potentiometer
R3—4700 ohms
R4, R6, R7—100,000 ohms
R5—25,000 ohms, panel-mount potentiometer

Capacitors
C1—0.22 μF
C2, C5—0.05 μF
C3—220 μF, 10 volts, electrolytic
C4—10 μF, 6 volts, electrolytic

Semiconductors
IC1—1458 dual op-amp
IC2—LM386 audio power amplifier

Other components
S1—SPST switch
SPKR—8–100 ohm miniature speaker



HITECH IBM PC/XT

Continued from page 102

The system we'll describe uses several multi-function adapter cards. That will allow us to leave open 5 of the 8 expansion slots. From a standpoint of comparison, the IBM PC XT without the addition of any monitor or display adapter card(s) already has 3 of the available 8 slots in use. The addition of the color graphics and monochrome display adapter cards will increase the load to an additional 2 slots leaving only 3 available slots for any accessories and expansions you might have in mind. The suggested parts listing and cost for the system is described in Table 5.

Note that our computer uses a parallel printer port rather than the RS-232C port present on the IBM PC XT. That doesn't mean that *you* have to. We made that choice because we already had a parallel printer on hand, and because we were using a plug-in modem card. But the combination floppy-disk controller/printer-port board is available in either configuration. One of the advantages of putting your own computer together is that you can control the selection and actual configuration of options for it.

Figure 3 shows the basic internal arrangement of the case. The case is of all metal construction with the needed brackets for mounting the drive(s) welded into position. The areas reserved for both the floppy drive(s) and the hard disk drive are supplied with pop-out plastic panel covers (front) which will be removed as the respective drives are installed

The first phase of construction will deal with the motherboard as shown in Fig. 4. During these steps we will:

- Configure DIP Switch SW1
- Locate and install the ROM
- Locate the power input connector
- Locate the RAM area and expand to 256K if desired.
- Locate power connector JP1

Position the board on your work surface with the expansion slots facing up and to your left. We will be setting configuration DIP Switch located near U20 on the PC board. Because of the possible variations in physical appearance of this switch, refer to Fig. 5 for guidance as to switch positions and settings. Your switch may or may not have the ON position marked. If it does not, ON will be in the position of the arrow. A ball-point pen might be useful in setting this switch.

We'll tell you how to assemble and configure your computer next time. But before wse go, let's mention that the parts listed in Table 5 can be obtained from: HiTech International, Dept. RE, 1180 Miraloma Way, Suite M, Sunnyvale, CA 94086. (408) 738-0601. **R-E**

LEAKAGE TESTER

continued from page 72

it only for the test purposes intended, and discharge tested capacitors with a screwdriver when finished. In addition, use of this project is recommended by technically qualified personnel only.

Now that that's out of the way, the unit is a cinch to use. Let's look at some typical applications for the project:

Testing capacitors is easy. If applicable, remove the suspect unit from the circuit first, as any external leakage can cause a good capacitor to test leaky. Set S1 to the DISCHARGE position. Then set S2 to the working voltage of the capacitor. If the voltage is greater than the project can provide, use the 100-volt position.

Then use insulated clips to connect the capacitor to the project.

Flip S1 to the CHECK position. The meter needle will "kick" upscale and drop to zero for a good capacitor. If desired, press S3 for more sensitivity; that will give you 0-1 mA readings instead of the nominal 0-10 mA readings.

Note that the meter needle may kick upscale many times before settling down. That indicates that the capacitor has excessive leakage at the test voltage and requires "forming." That is a common situation with capacitors that are used at a voltage far lower than the working voltage, like, say, a 50-volt part in a 12 volt circuit. That is not a fault of the project. However, if the meter doesn't stop kicking after several minutes, the capacitor isn't forming and should be replaced.

When the testing is finished, return S1 to the DISCHARGE position. The meter will read negative, indicating discharge. When the needle returns to zero, remove the capacitor.

So how much leakage should a good capacitor have? There is no simple answer, as it depends upon the capacitor type and circuit requirements. However, here are a few rules of thumb you can use.

Paper, mica, polyester, and tantalum capacitors should display no leakage. Electrolytic capacitors up to 50 μF should show less than 25 μA of leakage current. Electrolytic capacitors from 51 μF to 500 μF should show less than 50 μA leakage. Electrolytic capacitors from 501 μF to 1,000 μF should show less than 100 μA leakage. Electrolytic capacitors from 1,001 μF to 20,000 μF should show less than 500 μA leakage.

Another use for the project is forming new capacitors. Understand that electrolytic capacitors chemically deteriorate when they sit unused. The capacitor's electrolytic film, essential to capacitor operation, deteriorates, causing very high leakage currents. If you apply a voltage to the capacitor, the film can reform. But if that voltage is too high, that is, close to the device's rating, the film may not be able to form fast enough. So the capacitor will consume power, get hot, and possibly explode. Here's how to solve that problem:

Set S1 to the DISCHARGE position and S2 to the 3-VOLT position. Then use insulated clips to connect the capacitor.

Flip S1 to the CHECK position and note the meter reading. When the meter reads minimum current, change S2 to the 6-VOLT position. Continue increasing the voltage until the working voltage is reached. Discard any capacitor that takes over five minutes to form, or still has high leakage when checked at its working voltage.

Appliance safety is easy to check. Here's how: Set S1 to DISCHARGE and S2 to 100-VOLTS. Assuming the device to be tested uses a three-wire power cord, use an insulated clip lead to connect the "hot" side of the power cord to the positive binding post. After that, connect the ground lead of the power cord to the negative binding post. The return or common side of the power cord is unconnected. If the appliance does not use a three-wire power cord, connect the negative binding post to any exposed case screws or other metal surfaces on the unit to be tested.

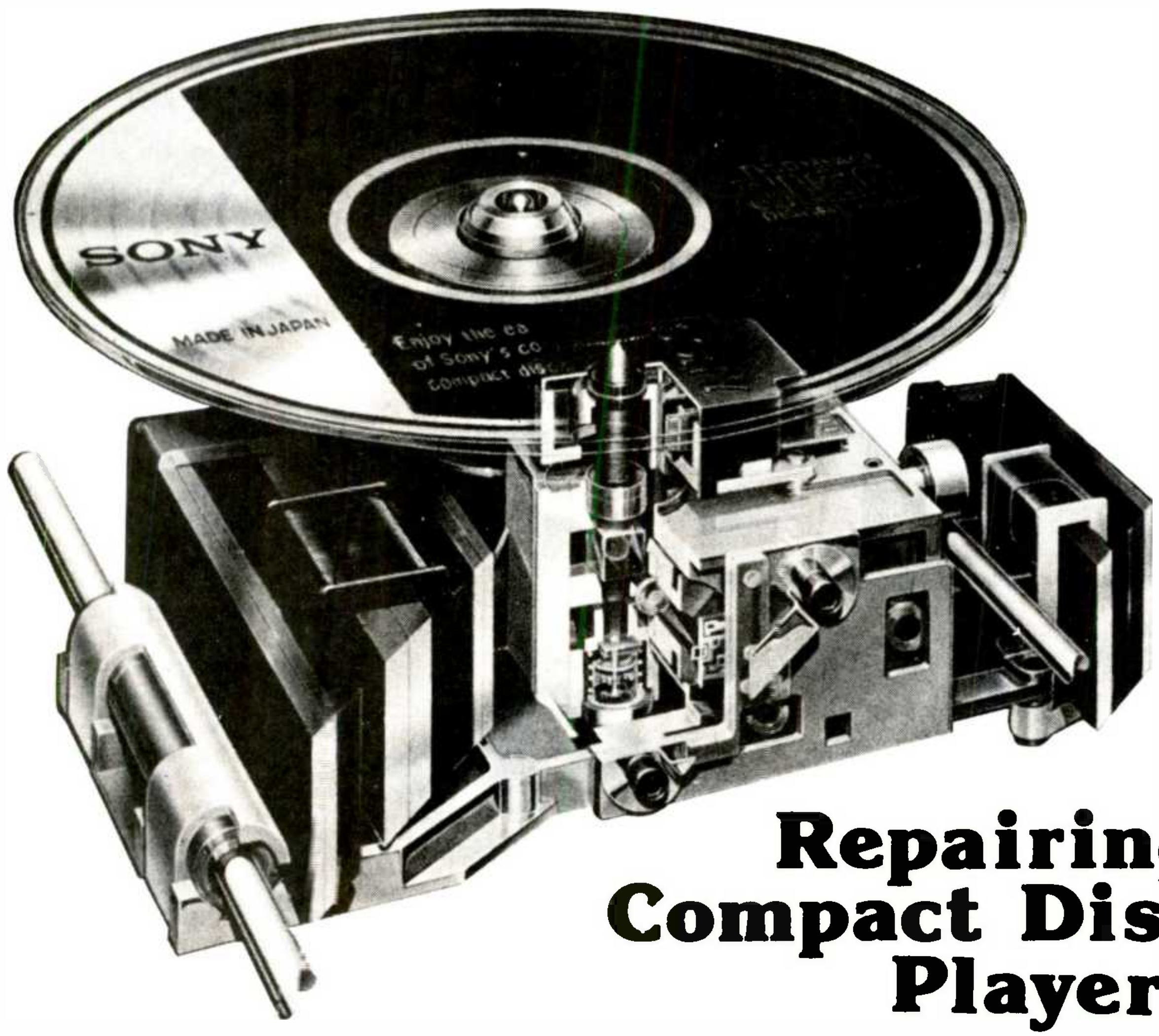
To test, flip S1 to the CHECK position. Press S3 for more meter sensitivity. The meter must read under 50 μA. For higher readings repairs are indicated.

Cables may be easily checked for leakage problems. Simply perform the checks the same way you did for appliance leakage. Remember to always connect the positive binding post to the center conductor and the negative binding post to the shield; that prevents a shock hazard.

If you need more sensitivity when performing leakage testing, try using your DMM if it has a 200-μA DC range. Simply set it to the 200-μA range and connect it in series with the positive binding post and the cable under test. That technique works great for other applications, except testing high-value capacitors. With those, when you switch to DISCHARGE, the current from the capacitor passes through the DMM, overloading it.

Another use for the project is quickly checking those special high voltage diodes used in TV sets and microwave ovens. Usually a DMM can't check those components because it can't supply enough voltage to turn on the device.

To test the diode, set S1 to DISCHARGE and S2 to 100-VOLTS. Then remove the diode from the circuit and connect it to the project's binding posts. Flip S1 to CHECK and note the reading. Then return S1 to DISCHARGE and reverse the diode. Flip S1 to CHECK again and note the reading. With most silicon diodes we expect a full-scale reading when the diode is connected one way and zero when it is reversed. With selinium diodes, the difference should be at least 100 to 1. **R-E**



Repairing Compact Disc Players

When CD Players burst upon the scene, any repairs had to be referred to the manufacturers. Nobody else knew diddly-squat about them. Sure. They sounded GREAT when they worked right, but before long, they started to develop problems. Unlike standard records, there were no grooves. A laser beam tracked in the surface below the surface. It was a whole new ball of wax, and without the wax!

Can YOU restore a Compact Disc Player to whole and healthy operation? There are two requirements, and you have both of them. The first is an inborn curiosity about things electronic. You obviously have that, or you wouldn't be reading this advertisement in this publication! The other thing you need is information. And you can get all the info you need simply by filling out the coupon below and mailing it in with the small fee.

By return mail you will receive a thorough, detailed treatise on the repair of Compact Disc Players. It's all you need to know, and written so that it's easy to follow. This information, plus your own skills as a technician will make you the complete authority on this new subject. You'll learn: Preventive maintenance techniques. How to diagnose problems. How to make repairs. Adjustments to keep your unit operating. Tune-Ups for maximum performance. Areas to avoid.

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PEST REPELLERS

continued from page 93

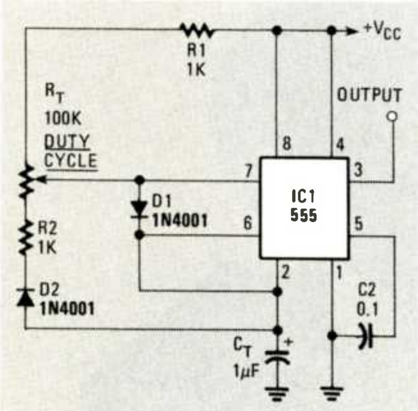


FIG. 4—IF YOU WISH TO VARY the duty cycle while keeping the frequency constant, replace the timing resistors with a single potentiometer.

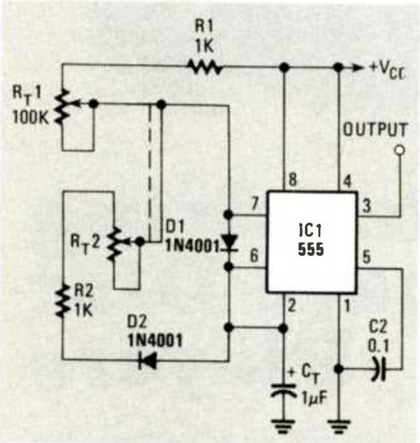


FIG. 5—IF YOU WISH TO VARY the frequency, but keep the duty constant, at about 50%, the 555 circuit can be modified as shown.

equal at all times.

Returning to our basic circuit, the power amplifier, IC3, may be any convenient type with response reaching into the ultrasonic region. You might consider using a low-power IC amplifier such as the Sprague ULN3705 or 3784B, or the National LM380, LM383, or LM384.

The output transducer may be an inexpensive tweeter. Piezoelectric types should be given special preference. You'll find several approriate transducers listed in the catalogs put out by many of the mail-order firms advertising on the back pages of this magazine.

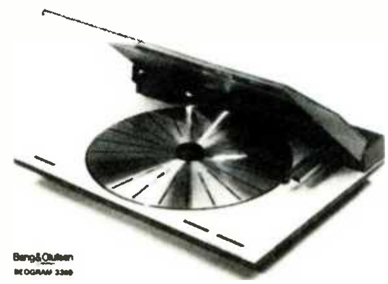
When experimenting with ultrasonic frequencies, be aware that if the frequency is too close to the audible range, the signal may be annoying, and possibly painful, to house pets and some people—particularly girls and young women. Due to the nature of ultrasonics, those effected may not be aware of the source of this discomfort. So, be alert to the condition of those around you when you are experimenting. **R-E**

NEW PRODUCTS

continued from page 8

Turntable

The Beogram 3300 from Bang & Olufsen of America is a moderately-priced, state-of-the-art unit. Designed as a part of the B&O remote-controlled Beosystem 3300 multi-room music system, it uses Datalink, a proprietary, interactive technology to allow intelligent, two-way communication with other system components. The turntable has an elegant tapered design with black plexiglass and brushed aluminum finish. This continues the classic styling that has been honored in museums worldwide.



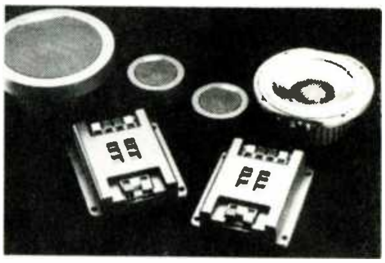
CIRCLE 62 ON FREE INFORMATION CARD

To simplify locating a particular cut in the record, the arm can be moved in ¾-inch increments, forward or backward. This can, if so desired, be done by remote control. A built-in light automatically illuminates the record surface during cueing, to aid in absolutely precise positioning.

Platter speed is controlled to an accuracy of 2%, regardless of line-voltage changes. The unit is priced at $399. Additional information is available from Bang & Olufsen of America, 1150 Feehanville Dr., Mount Prospect, IL 60056.

Car Speakers

The Model ALS-525 two-way component automotive loudspeaker systems will handle high power with low distortion. The units boast a crossover module that provides a two-position mid-range frequency control and three-position high-frequency level control for optimized performance. Because the woofers, satellite tweeters and crossovers are separately mountable, the ALS-525 provides greater versatility and flexibility with a variety of user-selectable options as far as placement is concerned.



CIRCLE 63 ON FREE INFORMATION CARD

The components of the ALS-525 consist of 5¼-inch woofers, ¾-inch dome tweeters, and crossover networks. Altec Lansing's carbon-fiber cloth, long-throw high-compliance woofer cones and polymide dome tweeters with ferroflouride cooling are used in the new ALS-525 speaker systems.

Suggested retail price for the ALS-525 has been set at $250 per pair. If you'd like additional information, contact Altec Lansing Consumer Products Division, Milford, PA 18337.

In-Dash Speakers

Three-and-one-half inch loudspeakers for in-dash use come with a special flange adapter with several holes. This makes installation easy on any American or foreign car. Four-inch by six-inch adapter plates allow the speaker, named the ALS-35, to be used as a substitute for four-inch by six-inch speakers also.

The ALS-35 can handle 15 watts nominal, 30 watts maximum. The usable frequency response ranges from 90 Hz to 20 kHz and the sensitivity is 88dB at one watt/meter. Impedance is four ohms.

CIRCLE 64 ON FREE INFORMATION CARD

The unit's total harmonic distortion measures in at one watt from 130 Hz to 17 kHz.

Suggested retail price is $70/pair. For additional information, contact Altec Lansing, Inc., Milford, PA 18337.

NEW PRODUCTS

Bookshelf Speakers

Two bass-reflex speaker systems from Revox of Switzerland, dubbed the Forum MKII and the Plenum MKII offer some fine performance features. For example, to help eliminate sound-swirling associated with right-angled edges, the new speakers use chamfered edges which are claimed to aid sound propagation around the enclosures. Other enclosure improvements include a high-density particle-board construction and ingenious rib-and-chamber reinforcement structures.

CIRCLE 90 ON FREE INFORMATION CARD

The midrange speaker is tightly enclosed in an assymetrical chamber to avoid internal standing waves. Removable speaker grilles are designed to be totally sound transparent in all directions and at all frequencies.

Both the Forum MKII and the Plenum MKII are three-way bass-reflex designs. The Forum, the smaller of the two, measures 13 inches wide, 19½ inches, high, and 13⅘ inches deep. It has a capacity of handling 150 watts music power. It has a 9½ inch woofer, a 3¼ inch midrange, and a ¼ inch tweeter.

The Plenum MKII is slightly larger, measuring 13½ inches wide, 22¼ inches high, and 13¼ inches deep. Capable of handling 170 watts, the unit contains a 10⅕ inch woofer, a 4½ inch midrange, and a 1-inch tweeter.

Special lacquer coatings have been used on the midrange and woofer cones that result in stiffening for the bass and damping for the midrange. The one-inch dome tweeter is made of pure titanium for low mass, high velocity and improved heat dissipation.

Prices start at $550. For additional literature or information, contact Revox Div., Studer Revox America, Inc., 1425 Elm Hill Pike, Nashville, TN 37210.

CD Player

A compact disc player with 16-bit resolution, four times oversampling, two D/A converters, and dual (separate anolog and digital) power supplies, has been introduced by dbx. Named the dbx DX5, it also offers advanced error processing in software and transport design, two-band OverEasy compression, two-band Impact Recovery, ambience control and full-function remote.

CIRCLE 91 ON FREE INFORMATION CARD

Each of the four signal-processing circuits is independently bypassable. These include Compression, Impact Recovery, Increased Ambience and Decreased Ambience.

DAIR, Digital Audio Impact Recovery, is a two-band design that adds impact to musical transients.

Compression is a two-band control for background listening, making car cassettes, and for easier taping of CDs.

Ambience Control adds or subtracts left/right (difference) information in midrange and treble to increase or decrease stereo separation and spaciousness of the sound field.

Also provided on the dbx DX5 is a headphone jack and a volume control. It is rack-mountable, and measures 17⅛-inches wide, 11⅞-inches deep, and 3½-inches high. It is priced at $699. suggested retail. For additional information, contact dbx, PO Box 100C, Newton, MA 02195.

More CD Players

Available now at a suggested retail of $280., is the Model DCD-300 from Denon. This is the least-expensive player Denon has ever produced. At only 14-inches in width, it is also Denon's most compact. Like the top-of-the-line Denon players, it offers such sophistication as a Super-Linear Converter, independent power supplies for digital and analog sections, and an isolated pickup subchassis. Convenience features include 15-selection programming, repeat track, timer play, and audible fast search.

CIRCLE 92 ON FREE INFORMATION CARD

For additional information on the DCD-300 and other components in the Denon line, write to Denon America, Inc., 27 Law Drive, Fairfield, NJ 07006, or call them at 201/575-7810.

BURGLAR ALARM

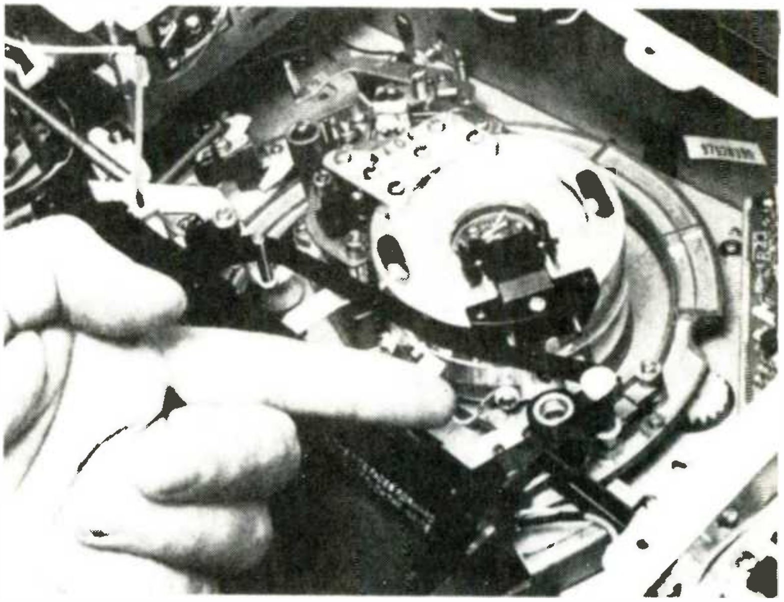
Continued from page 116

Begin by drilling holes for the two LED's and the key switch; also drill two mounting holes. Be careful, as a neat, "professional" looking job will help enhance the effect. Next, secure a "C"-cell battery holder to the panel using RTV adhesive; the holder should be located just below the holes for the LED's. Then mount the key switch in the appropriate hole. Wire the switch and the battery holder to the appropriate points on the board, keeping lead lengths as short as possible. Bend the LED's 90° so that they are parallel with the board. Position the LED's in the holes you previously drilled for that purpose so that they protrude about ⅛ inch. Finish up by securing the board to the top of the battery holder with a piece of double sided tape. Fig. 3 shows how it should look.

The unit can be installed just about anywhere. We suggest mounting it in your door frame for a professional look.

Although the circuit doesn't actually do anything, you should make it a habit to "arm" and "disarm" it as appropriate. That little bit of theater will help convince a burglar who is "casing" your home that it is indeed protected as advertised. R-E

VCR



REPAIRS AND ADJUSTMENTS THAT YOU CAN DO

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If you haven't, you'd better send for yours right now! The Videocassette Recorder, once a rarity, has become ubiquitous. They're all over the place. It seems that almost everybody that has a TV set has a VCR to go with it. And why not? Blank tape is inexpensive and with a VCR you can record programs to watch later, another day, or keep forever. Forever? NOTHING is forever! And those VCRs are starting to break down. Sure, you can run a head cleaner through the machine, but if that doesn't fix what's wrong, what do you do next? Remove the cabinet and start looking for burned resistors? What if you don't find any?

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Whether you repair VCRs for a living, or as a hobby, or just want to know what to do when your own unit fails, this book is for you. The first time you refer to it, it will pay for itself three times over. If you doubt *that* statement, check on the fees that VCR repair people are demanding these days. Don't wait until it's too late. Fill out the coupon below and send it right in. You won't be sorry.

Radio-Electronics©

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PC SERVICE

One of the most difficult tasks in building any construction project featured in **Radio-Electronics** is making the PC board using just the foil pattern provided with the article. Well, we're doing something about it.

We've moved all the foil patterns to this new section where they're printed by themselves, full sized, with nothing on the back side of the page. What that means for you is that the printed page can be used directly to produce PC boards!

Note: The patterns provided can be used directly only for *direct positive photoresist methods.*

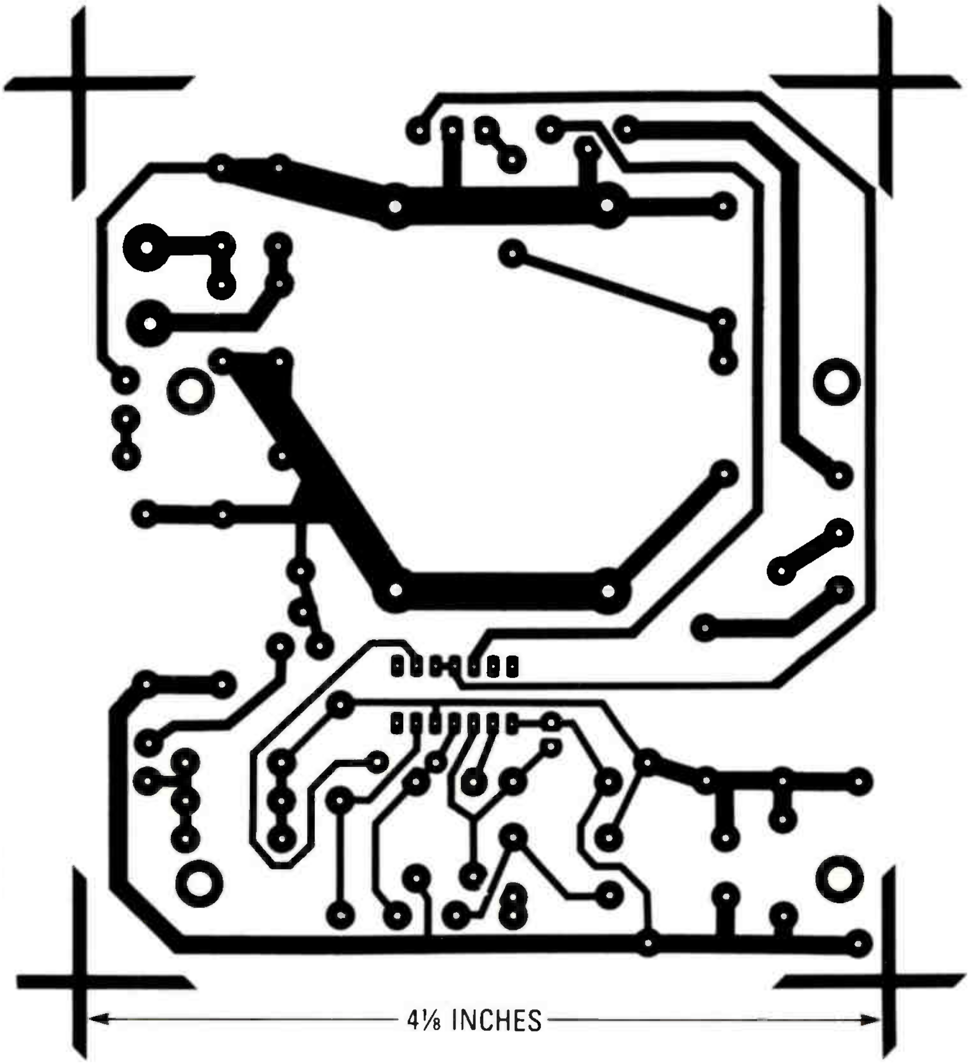
In order to produce a board directly from the magazine page, remove the page and carefully inspect it under a strong light and/or on a light table. Look for breaks in the traces, bridges between traces, and in general, all the kinds of things you look for in the final etched board. You can clean up the published artwork the same way you clean up you own artwork. Drafting tape and graphic aids can fix incomplete traces and doughnuts, and you can use a hobby knife to get rid of bridges and dirt.

An optional step, once you're satisfied that the artwork is clean, is to take a little bit of mineral oil and carefully wipe it across the back of the artwork. That helps make the paper transluscent. Don't get any on the front side of the paper (the side with the pattern) because you'll contaminate the sensitized surface of the copper blank. After the oil has "dried" a bit—patting with a paper towel will help speed up the process—place the pattern front side down on the sensitized copper blank, and make the exposure. You'll probably have to use a longer exposure time than you are probably used to.

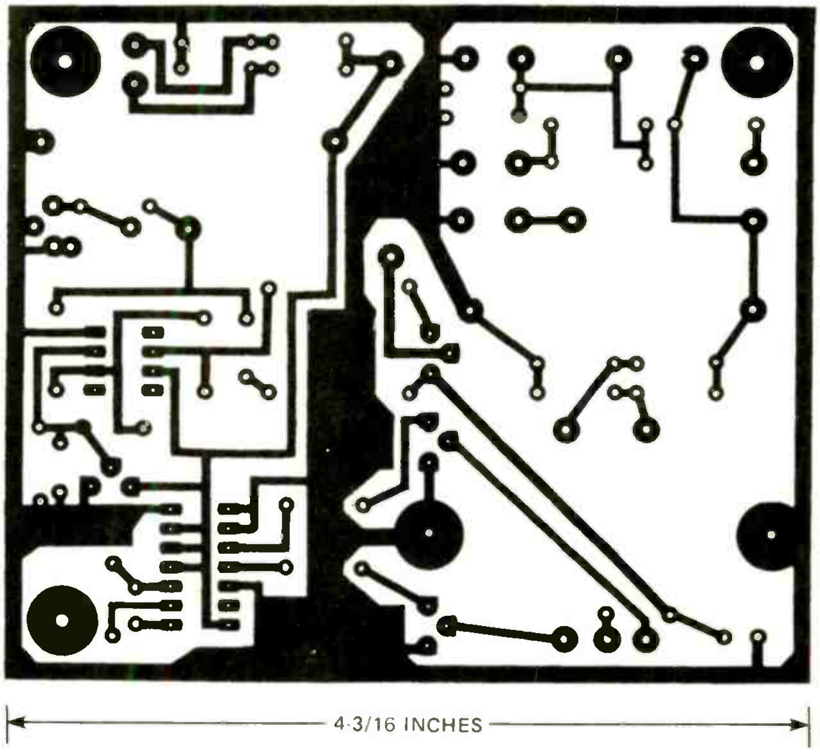
We can't tell you exactly how long an exposure time you will need but, as a starting point, figure that there's a 50 percent increase in exposure time over lithographic film. But you'll have to experiment to find the best method for you. And once you find it, stick with it. Don't forget the "three C's" of making PC boards—care, cleanliness, and consistency.

Finally, we would like to hear how you make out using our method. Write and tell us of your successes, and failures, and what techniques work best for you. Address your letters to:

Radio-Electronics
Department PCB
500-B Bi-County Blvd.
Farmingdale, NY 11735



IF YOU WISH to etch your own board for the 30-volt power supply, use this pattern.



BUILD OUR LITTLE LEAKAGE CHECKER and find the leaky capacitors that have been eluding your capacitor tester. The pattern for the PC board is shown here.

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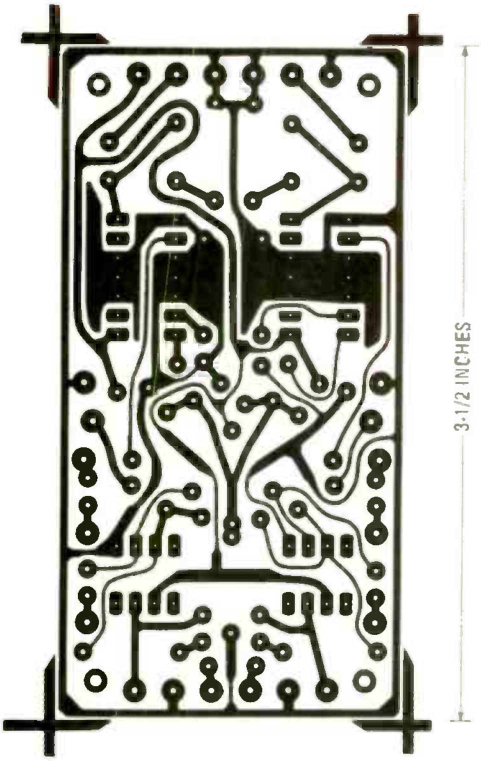
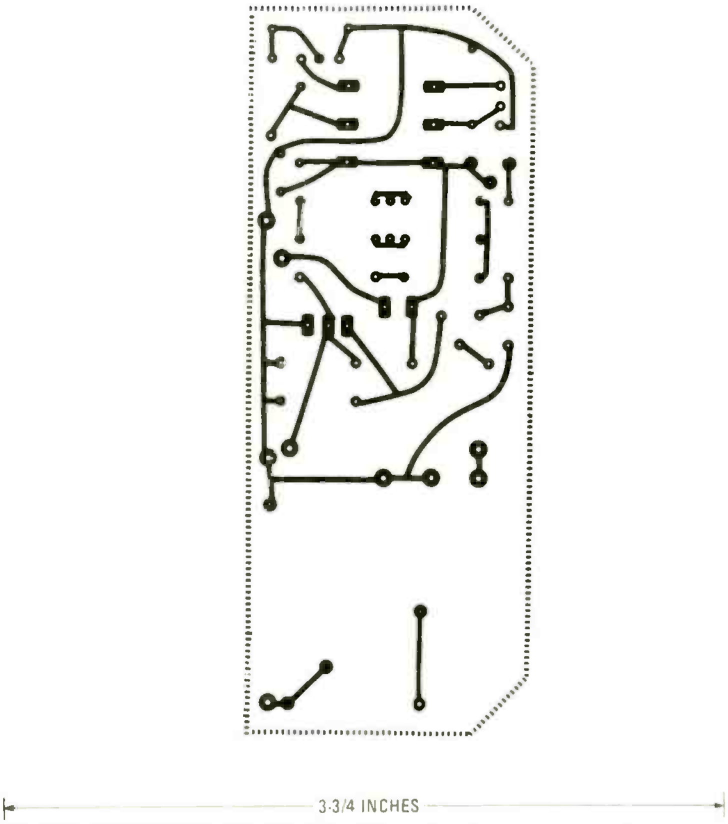
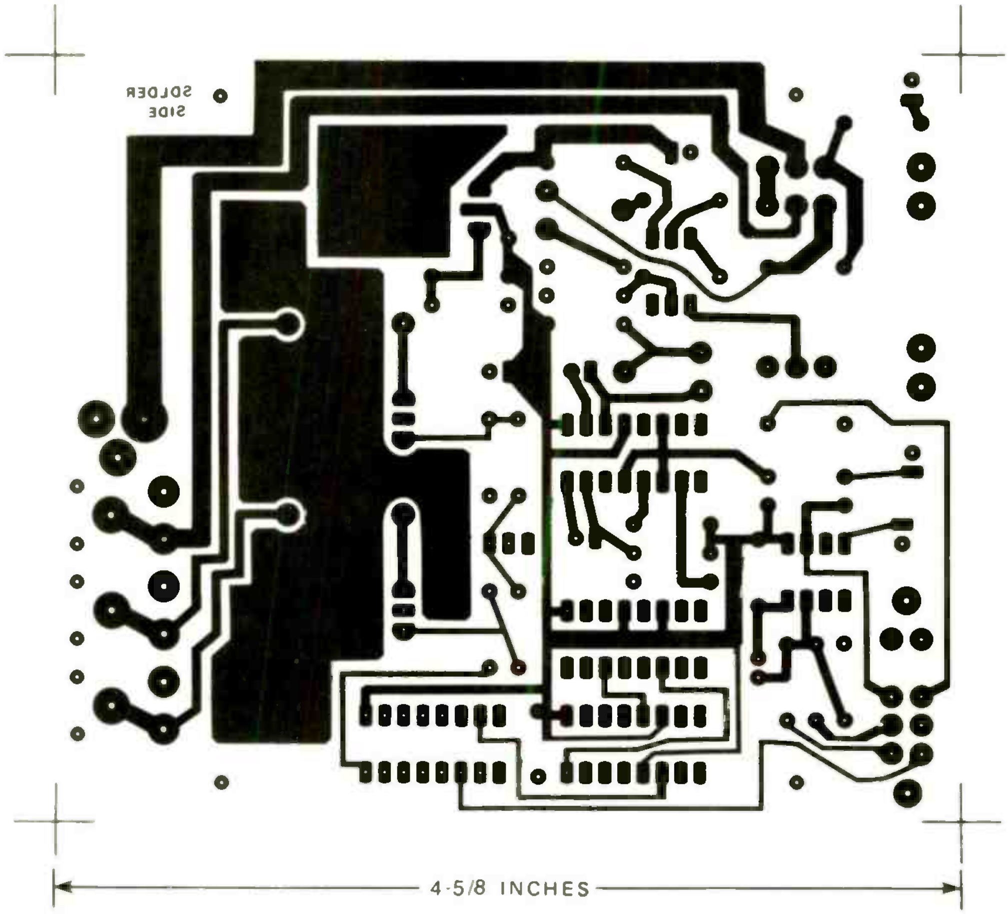


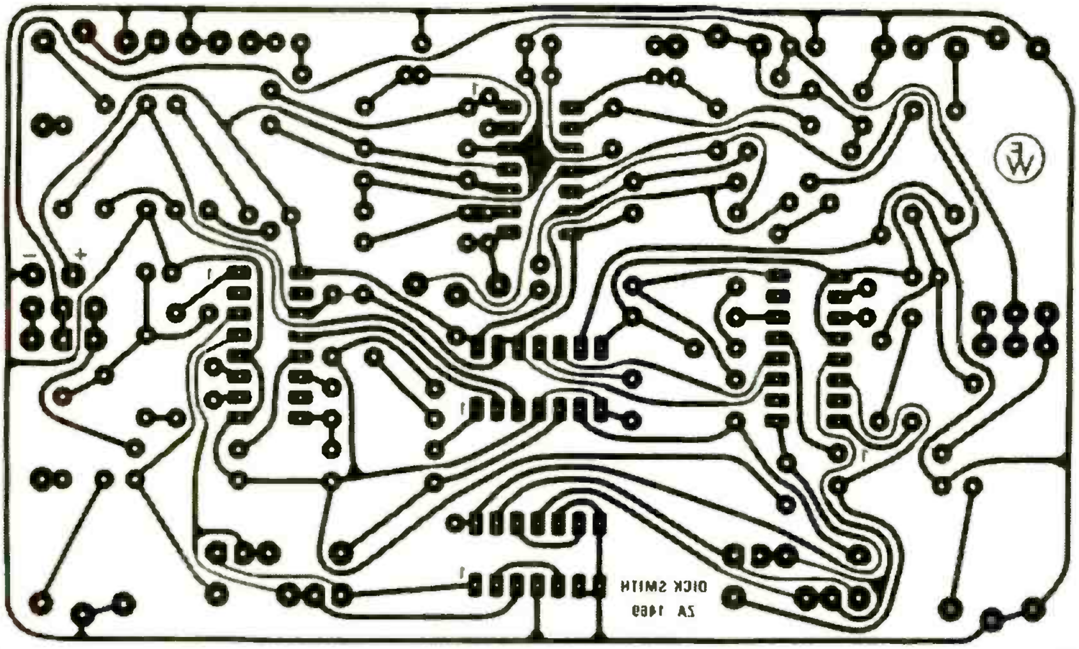
Get room-filling sound from your Walkman-type player with this easy-to-build amplifier.



SOLDER SIZE OF THE INFRARED VIEWER board is shown here in a full-size mirror image. This side goes toward the board to be exposed.

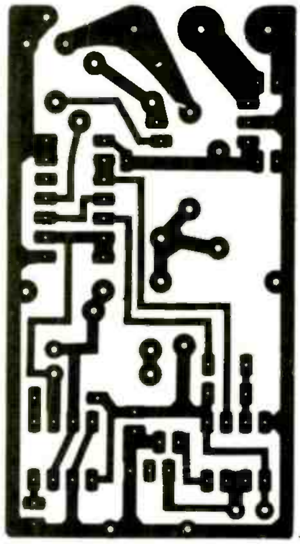


THE RADAR CALIBRATOR requires the use of a double-sided board. The pattern for the solder side is shown here.



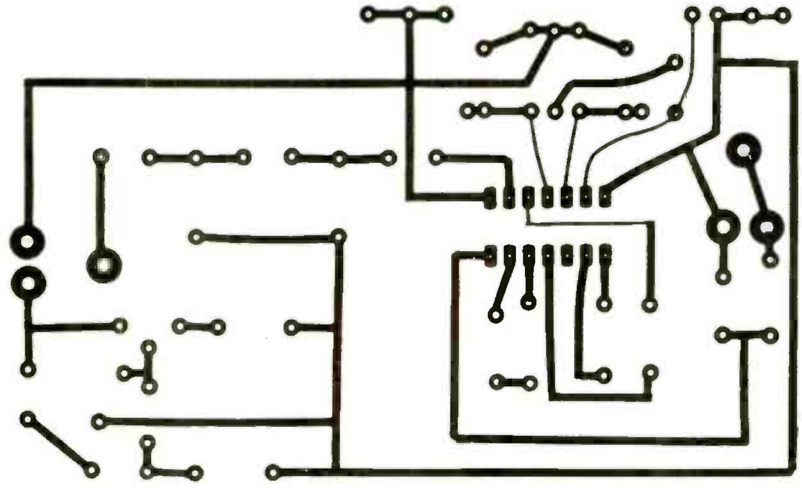
5½ INCHES

OUR MINI MUSIC SYNTHESIZER can turn anyone into a "one-man-band." The project is fun, and easy-to-build if you use the foil pattern shown here.



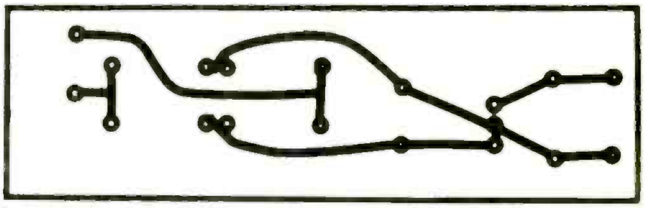
2¾ INCHES

KEEP AN EYE on the humidity with our humidity monitor. The PC board for that project is shown here.



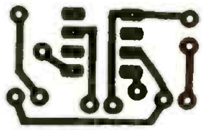
4-1/4 INCHES

HEAR YOUR FAVORITE TV SHOWS in stereo with our stereo-TV decoder. The main board is shown here.



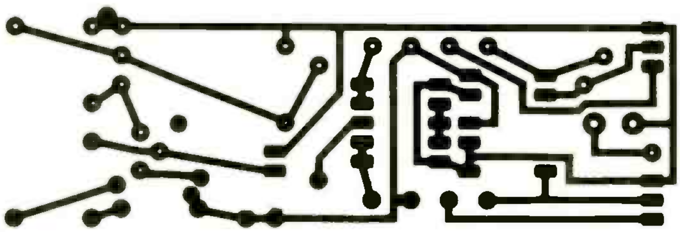
3-1/4 INCHES

USE THIS BOARD for the power supply required by our stereo-TV decoder.



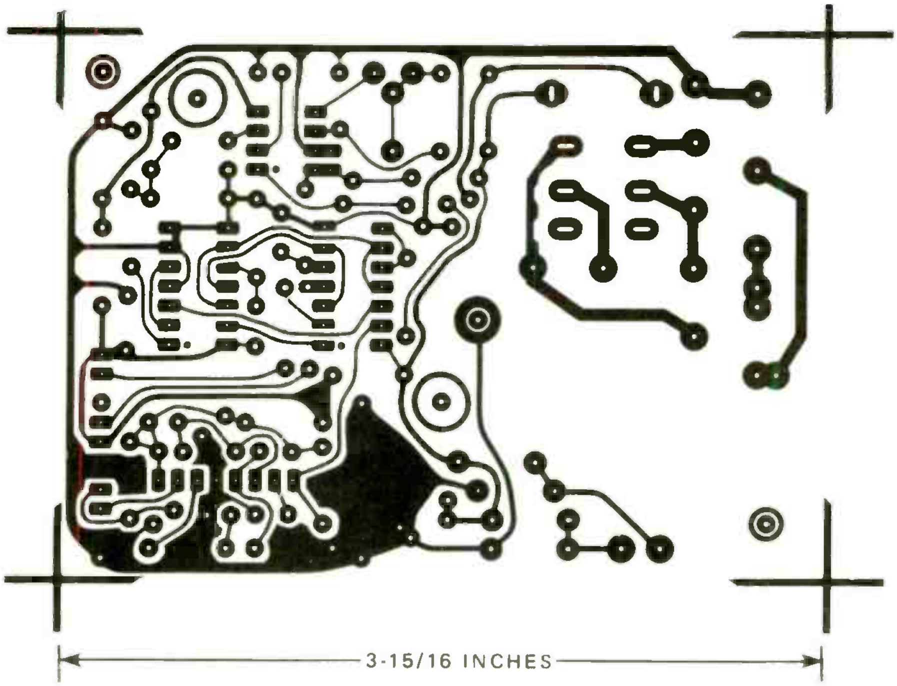
1 INCH

OUR ELECTRONIC SCARECROW can help chase away a less than determined burglar. If you choose to build that circuit on a PC board, here's a pattern that's appropriate.

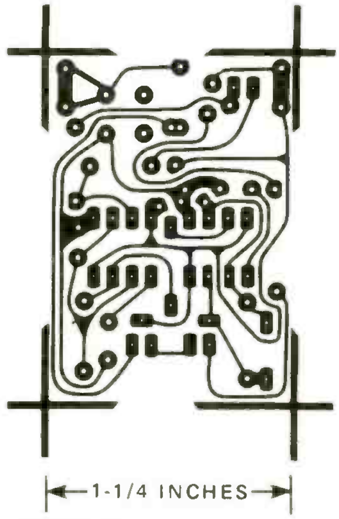


3-½ INCHES

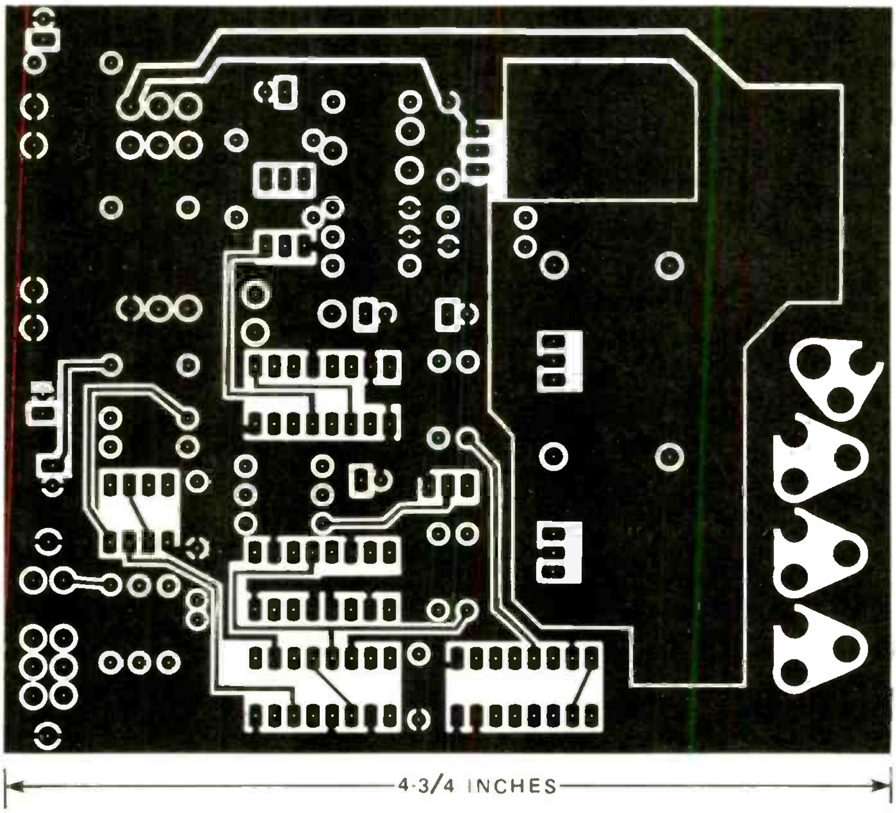
BECAUSE OF THE DANGEROUS VOLTAGES that the stun gun develops, be extra careful when laying out and etching this PC pattern for that circuit.



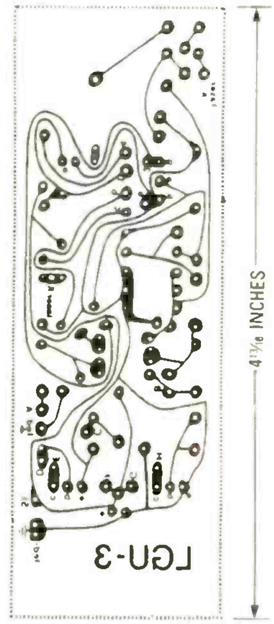
FREE YOURSELF from the tyranny of mechanical switches with our IR remote switch. The PC pattern for the receiver section is shown here.



PC PATTERN for the IR remote switch's hand-held transmitter



THE COMPONENT SIDE of the double-sided radar calibrator board is shown here. The solder side is found on page 145.



USE THIS board to build your laser.

1.2 GHz FREQUENCY COUNTER

Who says a frequency counter must be big and expensive? Our little counter can measure signals into the gigahertz range, and it can be built for under $60!

FRED HUFFT

THE PRICES OF VARIOUS TYPES OF TEST instruments have been dropping like ducks in a shooting gallery the past few years. The latest victim is the frequency counter. When digital frequency counters first appeared in the early 1950's they were very large, very expensive, and, by today's standards, very limited. However, inexpensive LSI frequency-counter IC's and high-speed ECL prescalers have been developed in the past few years.

Those IC's allow us to offer you a high-performance, hand-held frequency counter for under $60. It can measure the frequency of signals ranging from 1 MHz to 1200 MHz, and it has sensitivity under 25 mV throughout most of its useful range. In fact, using a 19-inch telescopic antenna, we can measure the output of a 1/10-watt, 146-MHz handie-talkie that is located more than 20 feet away! Our frequency counter has many other features rivalling units selling for several times its price. Complete specifications are shown in Table 1.

Design Philosophy

Our main design objectives were to produce a 1-GHz counter with good sensitivity, and with minimal size and cost. To meet those objectives we selected two key parts: Intersil's LSI frequency counter, the 7216D (IC1 in Fig. 1), and RCA's ECL prescaler, the CA3179 (IC2).

The Intersil IC was chosen because it contains all the circuitry necessary to count, generate gate signals, latch data, and drive a multiplexed LED display. It also has an MIP (*M*easurement *I*n *P*rogress) output, and control inputs for decimal-point placement and gate time.

The second key part is the RCA CA3179 amplifier/prescaler. It is an ECL part with an exceptional bandwidth of 1200 MHz and with excellent sensitivity. As you can see in Fig. 2, the CA3179's 500-MHz input has a sensitivity of about 10 mV rms above 100 MHz. Below that frequency, sensitivity is inversely related to frequency, rising to 125 mV at frequencies below about 2 MHz. As you can see in Fig. 3, the CA3179's 1200-MHz input is about 25 mV over the 300–1000-MHz range.

The CA3179 requires a single five-volt supply, and it runs barely warm to the touch. That makes it the only IC of its kind we know of that does not run hot in normal operation. Last, it is inexpensive and easy to find.

A few other inexpensive components round out our frequency counter. Refer-

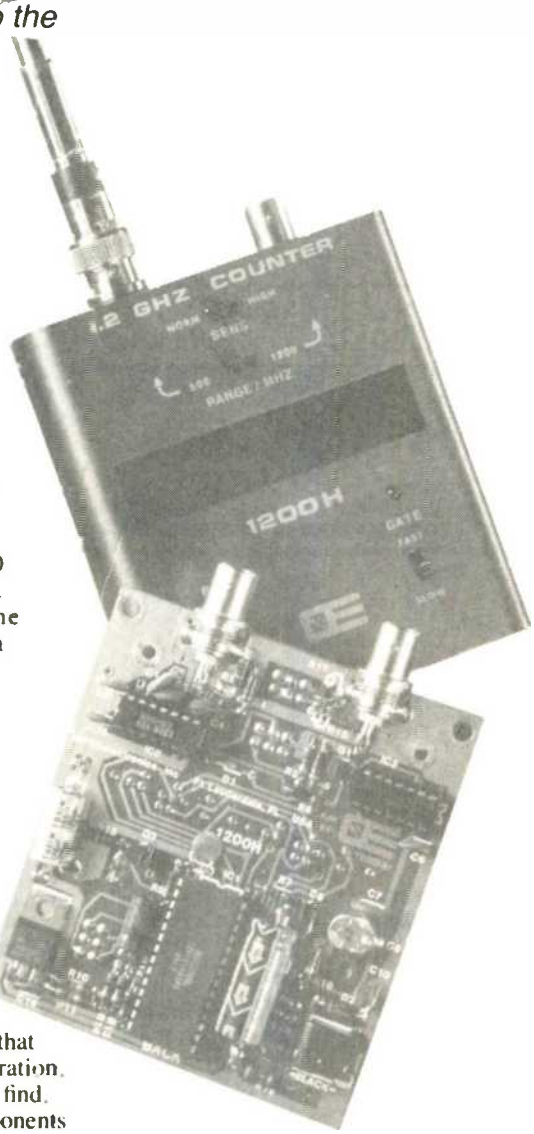


TABLE 1—FREQUENCY COUNTER SPECIFICATIONS

Range	1–1200 MHz
Gate time (fast)	0.25 second
(slow)	2.5 seconds
Resolution	100 Hz (fast gate time)
	1000 Hz (slow gate time)
Display	Eight 0.28-inch high, 7-segment LED displays, common-cathode. Decimal point indicates MHz. Leading zero blanking.
Sensitivity (1–10 MHz)	100–150 mV rms
(10–1000 MHz)	1–35 mV rms
(1–1.2 GHz)	10–150 mV rms
Accuracy	±1 PPM RTXO timebase,
	±1 count in LSD
Timebase aging	0.1 PPM/month
Input impedance	50 ohms
Gate LED	Illuminates during count
Input connectors	2 BNC female jacks
Input power	9–14 VDC, 150 mA, internally regulated
Optional battery pack	Six AA Ni-Cd cells (7.2 volts)
AC adapter and battery charger	9 VDC, 300–500 ma
Input power connector	⅛-inch jack, center positive
Case	0.060-inch anodized aluminum
Size	3.9 × 3.5 × 1.5 (inches)
Weight	8.5 oz, 13 oz with battery pack

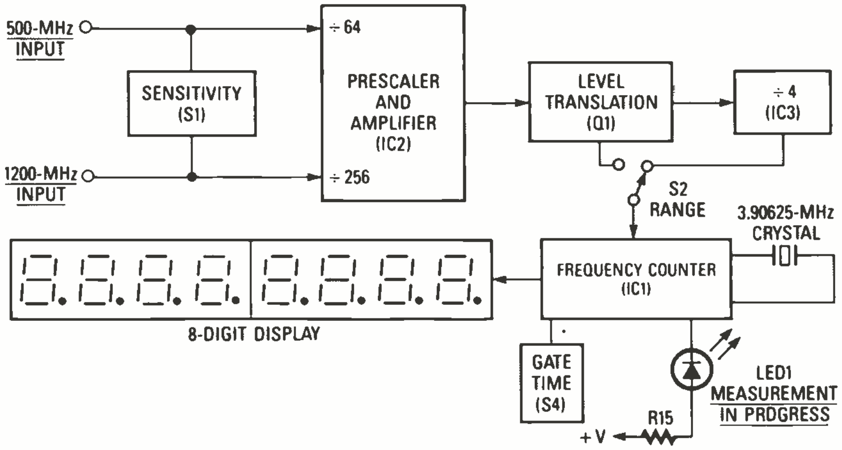


FIG. 1—BLOCK DIAGRAM OF THE FREQUENCY COUNTER reveals that only three IC's and a few discrete components are needed to produce a high-performance 1-GHz counter.

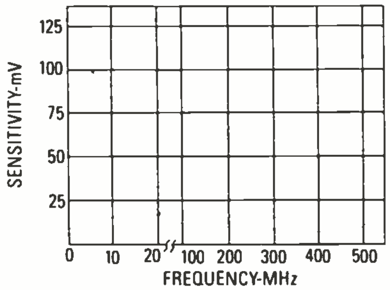


FIG. 2—RMS SINEWAVE SENSITIVITY of the CA3179's 500-MHz input is a flat 15 mV from 100 to 450 MHz.

ring back to Fig. 1, the output of the prescaler is fed through a level translator and then to two "D" flip-flops configured as a divide-by-four counter. We use a 74LS74 dual-D flip-flip because it is inexpensive and readily available, and because it uses little power. RANGE switch S2 allows you to select either the divide-by-four output or the direct output from the prescaler. Your chosen signal is then passed on to IC1, which processes it for output on the LED displays, two four-digit, common-cathode, multiplexed displays with 0.28-inch high digits.

The circuit is powered by an external AC adapter or an optional built-in Ni-Cd battery pack (which is trickled charged by the adapter). Separate switches are provided to control SENSITIVITY (S1) and GATE TIME (S4).

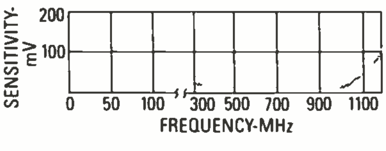


FIG. 3—RMS SINEWAVE SENSITIVITY of the CA3179's 1200-MHz input is a fairly flat 25 mV from 300 to 950 MHz.

Circuit Description

Referring now to the complete circuit diagram in Fig. 4, you can see that the output of the CA3179 is fed through the D1/Q1 circuit. Those components serve to boost the 1-volt output of the CA3179 to a standard TTL level. Then, depending on the position of RANGE switch S2-b, the signal is passed directly to the 7216, or through the divide-by-four circuit built from the two "D" flip-flops in IC3.

The other half of the RANGE switch (S2-a) controls the voltage at pin 3 of the CA3179. When pin 3 is high, the signal applied to pin 9 is fed through an extra internal divide-by-four stage before it is amplified and output on pins 4 and 5. When pin 3 is low, the signal on pin 13 is simply processed for output without being divided internally.

We use a 3.90625 MHz crystal for our time base; the crystal yields a *fast* gate time of 0.256 second. The displayed frequency equals the input frequency divided by 1000 in the *fast* mode. In *slow* mode, gate time is 2.56 seconds. The displayed frequency equals the input frequency divided by 100 in the *slow* mode.

Switch S4, GATE TIME, performs two functions. First it selects the appropriate gate time according to which digit output of IC1 the RANGE input is connected to. Another of the 7216's inputs is also controlled by S4: the DP SELECT input. The decimal point of the digit output to which that pin is connected will be the one that lights up. In our case, the correct decimal point illuminates, according to the position of S4, to provide a reading in MHz.

Self-oscillation

Due to the high gain, balanced-input amplifiers in the CA3179, self-oscillation can occur with no input signal present. The result is a random, constantly-changing count. Although that does not affect the performance of the counter, it can be distracting.

To settle the display we added SENSITIVITY switch S1 and the associated resistors and capacitors. When the switch is on, the RC networks eliminate display bobble. The difference in sensitivity varies with frequency. For example, at 150 MHz, normal sensitivity is typically 15 mV rms, and high sensitivity is about 6 mV rms. But at 850 MHz, normal sensitivity is typically 40 mV rms and high sensitivity is about 25 mV rms.

The MIP output of IC1 drives Q2, which in turn drives LED1. When it is illuminated, a measurement is in progress. The LED goes out for a fraction of a second between measurements.

For greatest accuracy, trimmer C8 can be adjusted so that the output of the oscillator is exactly 3.906250 MHz. For

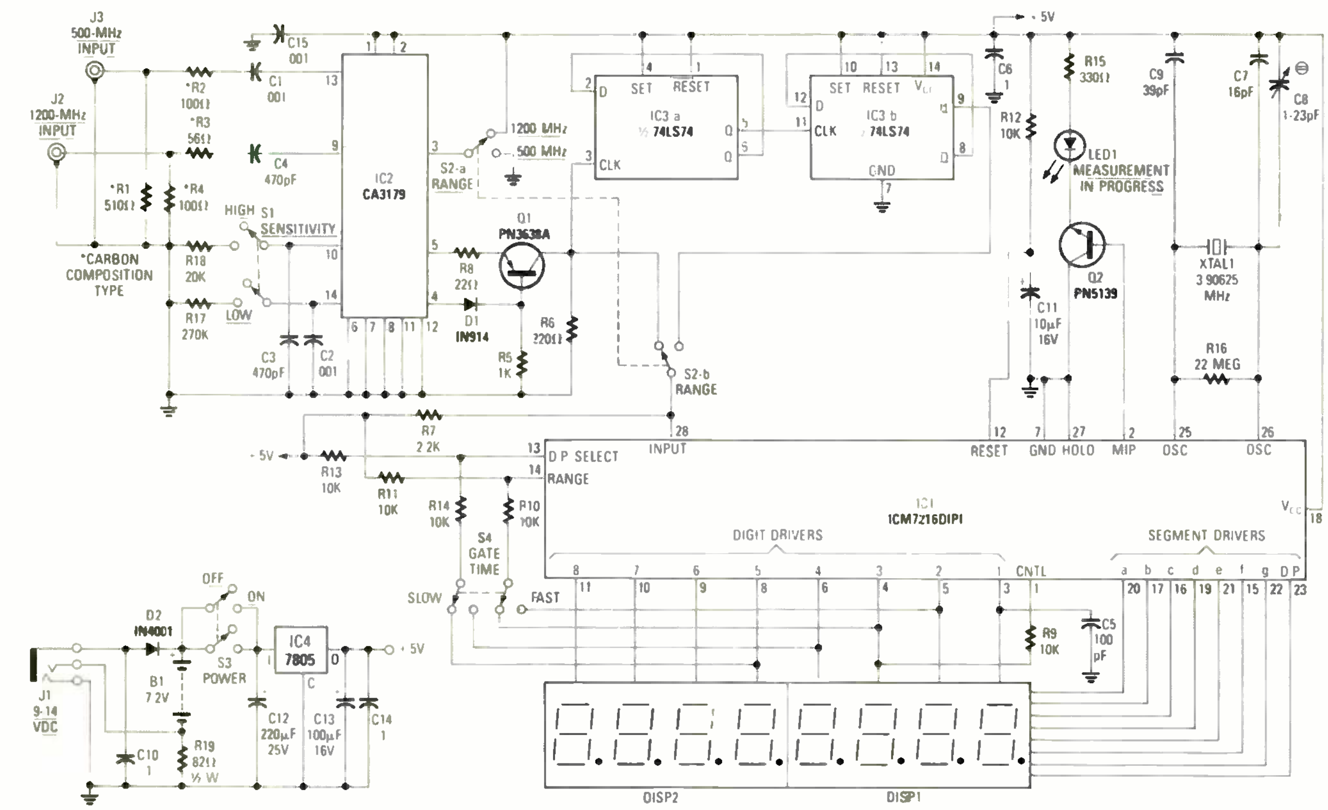


FIG. 4—SCHEMATIC DIAGRAM OF THE FREQUENCY COUNTER is a model of design simplicity. Transistor Q1 and associated discrete components translate IC2's ECL output into a TTL level for IC3 and IC1.

greatest frequency stability. C7 should be an NPO type, and C9 an N750. In case you're wondering, temperature causes almost no change in capacitance in an NPO capacitor; the capacitance of an N750 capacitor will decrease 750 parts per million for each 1°C increase in temperature.

The power supply is a standard 7805 circuit. Input voltage can range from 8–12 volts DC; input should never exceed 12 volts. Diode D2 protects the circuit from an accidental reversed-voltage input.

Power input jack J1 has a switch contact. When no plug is present, the contacts are closed, so the negative terminal of the battery is grounded. When a plug is present, R19 appears in the battery's ground circuit; that resistor is what provides trickle-charging. With a 9-volt input, a charge current of 25–45 mA will be provided. Charging occurs even when POWER switch S3 is off. You should ensure that charge current never exceeds 45 mA; adjust the value of R19 if necessary.

The Ni-Cd battery pack specified in the Parts List is rated at 45 mA. This means that a charge current of 45 mA will fully charge a completely discharged pack in about 14 hours, and that the batteries won't be harmed by continuous charging at that rate (or less). For maximum battery life and capacity, Ni-Cd's should occasionally be "deep cycled" several times by completely discharging and then fully recharging them. That should prevent a discharge "memory" from forming at less than the full rated output voltage.

Voltage regulator IC4 provides a regulated five-volt DC output when S3 is closed. Regulated voltage is especially important to the timebase oscillator, because, as the battery's voltage varied throughout its life, so would the frequency of the timebase. Erroneous measurements would result. With a good source of regulated voltage, however, the timebase circuit should maintain ±1-PPM stability at room temperature. Both temperature stability and accuracy are almost totally dependent upon the crystal used.

The counter circuitry by itself draws about 120 mA; in combination with the battery charger, about 150 mA will be drawn. The optional Ni-Cd battery pack should give up to 5 hours of continuous operation, which is more than adequate for most portable requirements. In any case, we recommend that your DC source be able to supply at least 300 mA for safe and reliable operation.

That's about all there is to the circuit—so let's build a frequency counter!

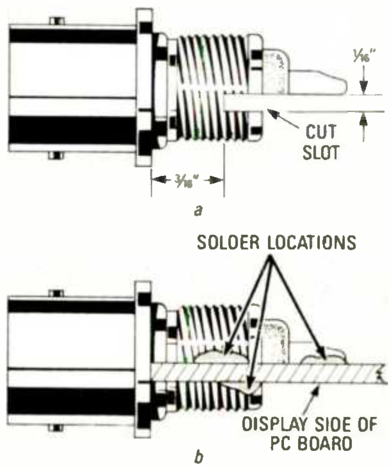


FIG. 5—A BNC CONNECTOR must be modified as shown in *a* so that it can be soldered to the PC board as shown in *b*.

PC board

For ease of construction, we recommend use of a double-sided PC board. You can buy an etched, plated, labeled, and solder-masked board from the source mentioned in the Parts List, or you can etch you own board using the foil patterns shown in "PC Service."

For flexibility, the PC layout has a number of extra pads and holes to accommodate capacitors of various sizes and shapes. That applies to C2, C3, and C4, and to trimmer C8. We designed a partial micro-strip layout for the input connectors (J2 and J3) to simplify assembly and to approximate a 50-ohm input impedance.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1—510 ohms, carbon composition
R2, R4—100 ohms, carbon composition
R3—56 ohms, carbon composition
R5—1000 ohms
R6—220 ohms
R7—2,200 ohms
R8—22 ohms
R9–R14—10,000 ohms
R15—330 ohms
R16—22 megohms
R17—270,000 ohms
R18—20,000 ohms
R19—82 ohms, 1/2 watt, 10%

Capacitors

C1, C2, C15—0.001 µF ceramic disc
C3, C4—470 pF ceramic disc
C5—100 pF ceramic disc
C6, C10, C14—0.1 µf ceramic disc
C7—16 pF ceramic disc, NPO
C8—1–23 pF trimmer
C9—39 pF ceramic disc, N750
C11—10 µF, 16 volts, electrolytic
C12—220 µF, 25 volts, electrolytic
C13—100 µF, 16 volts, electrolytic

Semiconductors

IC1—ICM7216DIPI universal frequency counter (Intersil)
IC2—CA3179 ECL pre-scaler (RCA)
IC3—74LS74 dual "D" flip-flop
IC4—7805 5-volt regulator (TO-220 case)
Q1—PN3638A transistor (ECG159)
Q2—PN5139 transistor (ECG108)
DISP1, DISP2—DL-4770, four-digit, seven-segment, common-cathode multiplexed display (Litronix)
LED1—standard red LED
D1—1N914 switching diode
D2—1N4001 rectifier

Other Components

S1–S4—subminiature DPDT slide switch
J1—⅛-inch power jack with switch
J2, J3—BNC connector, female, bulkhead mount, modified (see text)
XTAL1—3.906250 MHz crystal, parallel resonant, 22 pF, HC-18 case.

Miscellaneous ³⁄₁₆" high by ¼" OD nylon spacer, PC board, power pack, etc.

Note: The following items are available from Optoelectronics, Inc., 5821 N.E. 14 Ave., Ft. Lauderdale, FL. 33334 (305-771-2050): PC board (no. PCB-1200H), $16; Kit including PCB and all parts less cabinet (no. 1200HK), $59.95; Anodized cabinet with red lens (no. CAB-1200H), $20; Power adapter/charger (no. AC-1200), $7.50; Ni-Cd battery pack (no. NiCd-1200), $20; Telescoping RF antenna (no. TA-100), $12; Vinyl zipper case (no. CC-70), $10; 50-ohm 1×probe (no. P-100), $18; Wired, tested and calibrated counter (no. 1200H), $110; Wired, tested counter with adapter and power pack (no. 1200HC), $137.50. Individual components also available. Florida residents add 5% sales tax. All orders add 5% for shipping and handling.

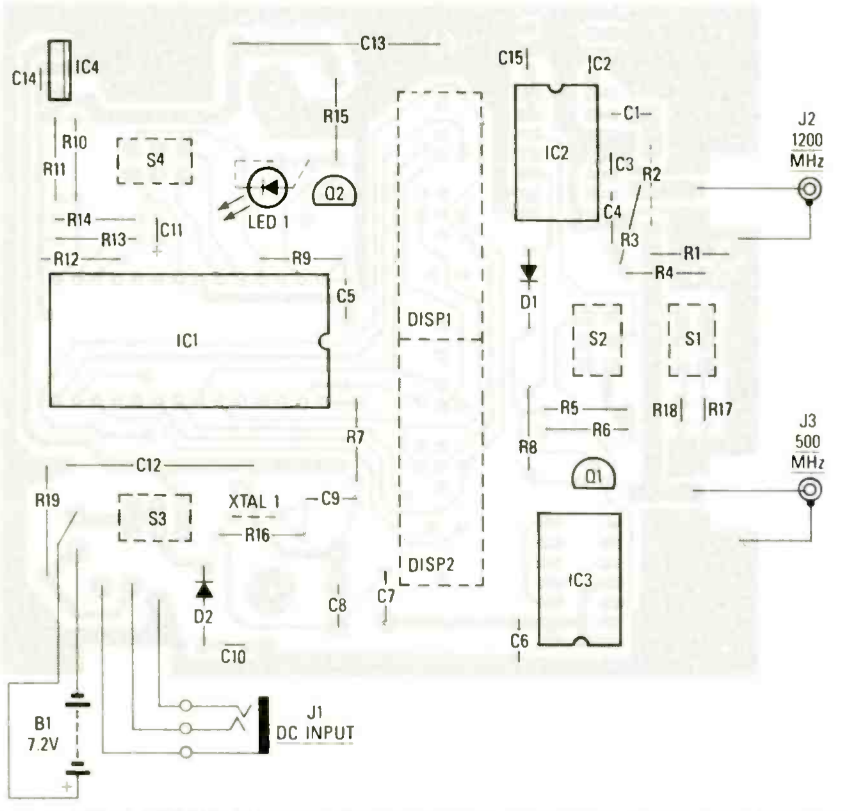


FIG. 6—PARTS PLACEMENT DIAGRAM. Most components mount on the bottom of the board. The switches, displays, R2 and LED1 are shown in dashed lines; they should be mounted on the opposite side of the board. The leads to the battery attach to the bottom side; BNC jacks J2 and J3 should be soldered to both sides of the board.

In addition, the PC board has two notches at the top to accept modified BNC connectors, and another notch along one side for the power-input jack J1. The notches for the BNC connectors should be 0.365" wide and 0.250" deep. The power-jack notch should be 0.430" wide and 0.150" deep.

Construction

Our frequency counter was designed for quick and easy assembly; by following the directions you should have no trouble building, testing, or calibrating the instrument. We'll call the "front" side of the board the side that the switches and the displays are mounted on.

First modify the two BNC connectors as shown in Fig. 5-*a*. Using a hacksaw or a modeling file, cut a ¹⁄₁₆-inch slot beneath the center post of the BNC connector, leaving ³⁄₁₆ of an inch beneath the flange. Then solder each connector to the board as shown in Fig. 5-*b*. The connectors are soldered to the adjoining ground planes on both sides of the PC board; that makes the installation both strong and well grounded. The center conductors of the BNC connectors should also be soldered to the PC board now.

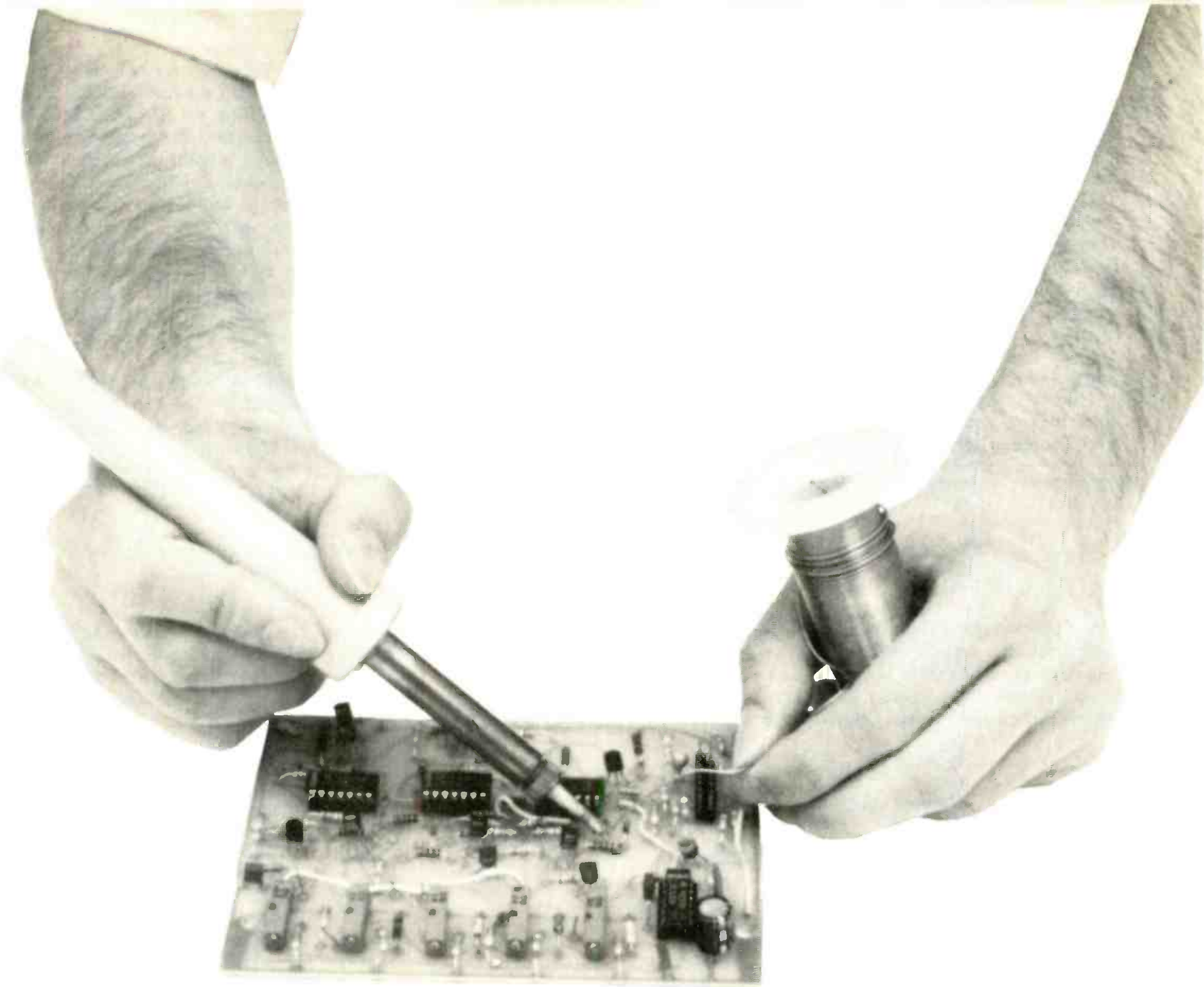
Next, on the back side of the board, as shown in Fig. 6, install the low-profile components (the diodes and resistors), followed by the IC sockets, then the capacitors, etc. Be certain to observe proper polarity when installing the diodes, the electrolytic capacitors, the IC sockets, the battery connector, and, on the front of the board, LED1 and the displays. By the way, we found almost no difference in performance with and without sockets, but using them makes servicing easier.

Since the counter will be dealing with rather high frequencies, R1–R4 and C1–C4 should be installed with minimum lead length. Also, resistors R1–R4 should be the non-inductive, carbon-composition type; the other resistors may be either composition or film types. Capacitors C1–C4 should be small ceramic disk or monolithic ceramic types. Install all input components neatly.

To complete the back side of the board, install the voltage regulator (IC4), trimmer capacitor C8, and all small capacitors. Bend the leads of the regulator so that its body is parallel to the PC board. A heatsink is unnecessary. Next install power jack J1 and transistors Q1 and Q2.

Clean flux off the front side of the board, and then install the switches, DISP1 and DISP2, XTAL1, LED1, and R2, according to Fig. 6. The LED should be mounted above a spacer ³⁄₁₆ inch in length. The displays should be mounted flush against the board. When installing the displays, the IC sockets, and any other components with numerous solder connections, it's best to solder two or three

continued on page 163



NEW IDEAS

• SLIDING-TONE DOORBELL • PLANT-WATER MONITOR • TROUBLE-TONE ALERT • CRYSTAL TESTER • BATTERY SUBSTITUTER • SPEAKER OVERLOAD PROTECTOR • MUSIC MAKER • CARPORT LIGHT CONTROLLER • LIQUID RESIN FLUX • RELAY MULTIVIBRATOR • VHF TONE TRANSMITTER • BOILER CONTROL •

Music Maker

MY NEW IDEA IS A TONE SEQUENCER WITH a variable tempo. A 555 timer operated in an astable mode produces the tempo. The 555's output clocks a 7490 counter which then drives a 7442. The 7490 counts from 0 to 9 in binary and sequences the 7442 from 0 to 9. The 1 output of the 7442 goes low when its binary equivalent appears at the 7442's input. The 7442's output goes through some tone resistors to another 555 which is the tone generator. Its output goes to an LM380 amplifier IC and to the speaker.

Here is a way you can choose a set of fixed tone resistors for the circuit. Connect one outer terminal of a 1000-ohm potentiometer to ground. The center terminal of the pot is connected to pin 1 of the 7442. Turn the circuit on and as soon as a tone appears, deactivate the 555 clock by disconnecting pin 14 of the 7490. If you deactivate the clock circuit as soon as the tone burst is heard you can then start the programming procedure. When a fixed tone is heard from the speaker, rotate the pot's shaft until the desired tone is heard. Then disconnect the pot from the circuit and measure the resistance with an ohmmeter. You can then replace the pot with a fixed resistor. You then repeat the procedure for the rest of the outputs of the 7442.

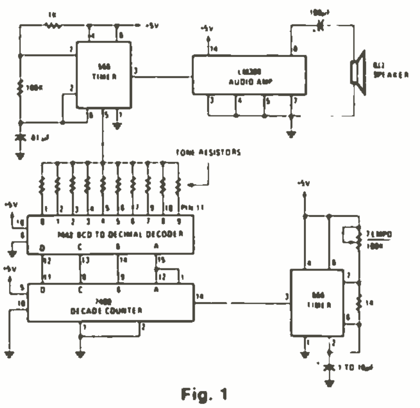


Fig. 1

The original circuit (see Fig. 1) was breadboarded but any method of construction may be used to build a working device.—*Mark Dittmar*

Automatic Light Controller For Carport

MY WIFE WORKS EVENINGS AND GETS home well after dark. Because no one is at home to greet her upon her return, we used to leave the carport light on for many energy-wasting hours, just so she could avoid tripping over bicycles or stepping on the dog's tail when she returned in the evening.

To save my marriage—and conserve electricity—I devised the following circuit. It is simply a 555 timer IC, operating in the one-shot mode, that is triggered by light striking photoresistors. These normally have a resistance of several megohms but, in the presence of light, that resistance drops to several hundred ohms, permitting current from the six-volt source to flow in the circuit. The R–C combination shown gives an on-time of about two minutes. Photoresistors PC3 and PC4 are mounted at headlight-height on the carport wall (one for each of our two cars).

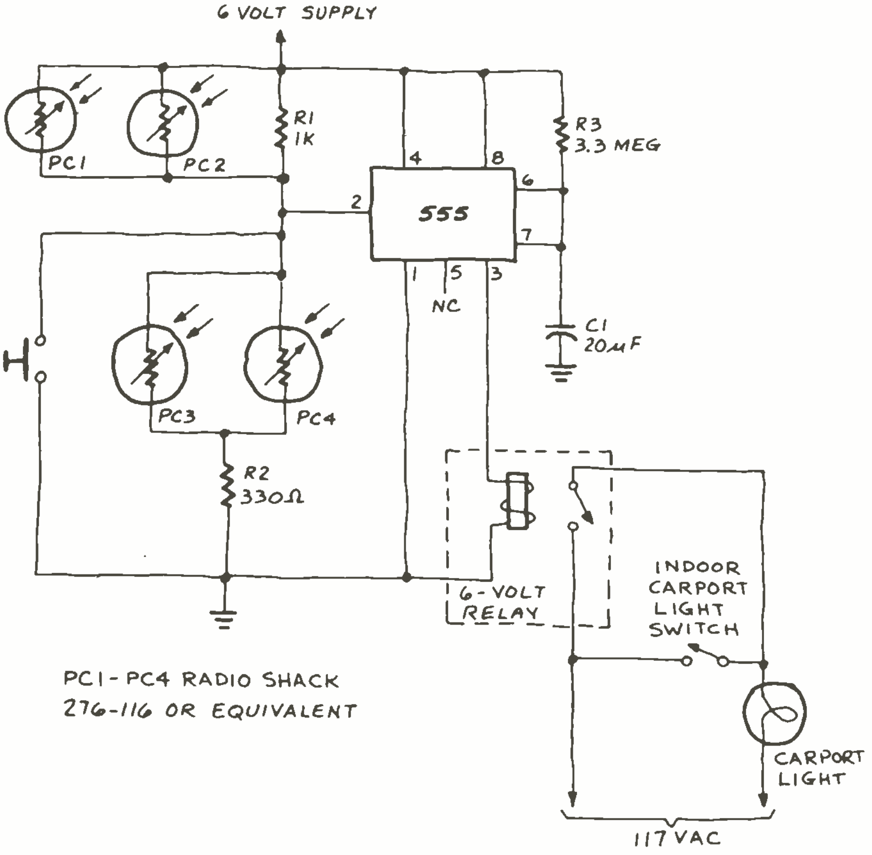


FIG. 1

Now, when my wife pulls into the carport at night, the headlights illuminate the photoresistor, and the timer starts. That actuates a relay, RY1, in parallel with the carport light switch, and the lights are turned on long enough for her to get safely into the house. The lights are automatically turned off when the timer's two minutes are up.

We also have a push-button switch mounted inside the house and, when we go out at night, that allows us to turn on the outside lights to see our way out to the car, knowing they'll turn themselves off after we've left.

Photoresistors PC1 and PC2 are mounted on the outside of the house where they are in the sun much of the time. That keeps the timer from triggering during daylight hours. Resistors R1 and R2 establish the thresholds for proper on/off control.

My unit has been in service for over a year and has not given me any problems. I've also installed quite a few of these for friends, and they are pleased as can be.

All the components used are stock items.—*Ronald Picard*

Trouble Tone Alert

I DESIGNED THIS SYSTEM FIVE YEARS AGO for use in my service business, and it works great. I use it to look for intermittent problems on my bench. For example, if I had a color TV whose horizontal output current would go way up at unpredictable times, and I didn't want to sit by and wait for this to happen, I'd hook up the tone alert and let it tell me when the current increase took place.

The Trouble Tone Alert is intended for use with analog meters—just wire a "mini" earphone jack directly across the meter movement, plug it in, and you're all set. The high impedance of the alert keeps it from affecting the accuracy of the meter reading, because most meter movements are on the order of 1800 ohms and the input impedance of the alert is in the megohm range.

This device is as versatile as your meter, since all it reacts to is the meter-movement driving voltage. It will respond to a change in AC or DC voltage, current, or in resistance.

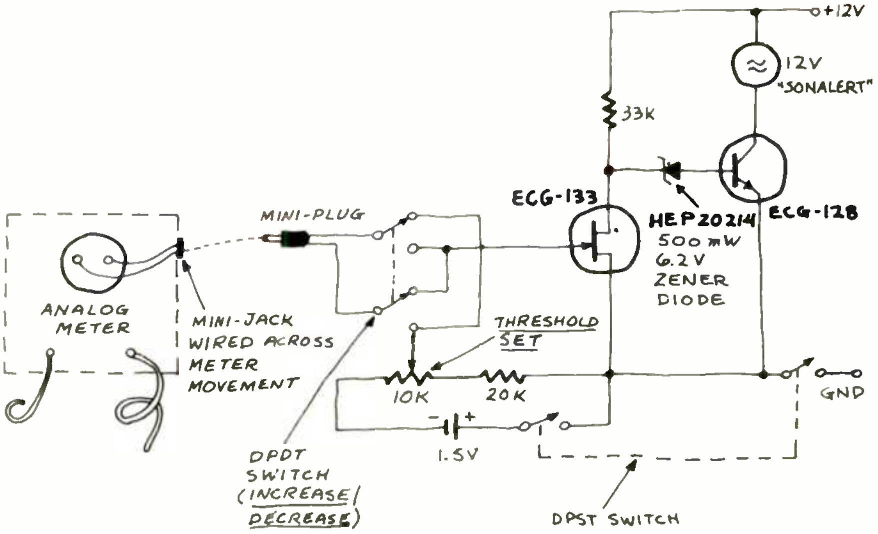


FIG. 1

You tell the Trouble Tone Alert whether to look for an increase or decrease by means of the DPDT switch and adjust the threshold control until the tone from the Sonalert just disappears (with the meter in the circuit being tested, of course). After that you can go about your business and wait for the alert to signal you when your intermittent problem has finally shown up.

John J. Augustine

Crystal tester

IF YOU FREQUENT HAMFESTS, ELECTRONICS flea markets, or any other type of surplus outlet, you know the pros and cons of buying from those sources. On the one hand, they're an excellent source of hard-to-get parts as well as a haven for bargain hunters. On the other, however, just about everything is sold "as is," with no guarantee of any kind—it's strictly "let the buyer beware." If you've ever come home with a pile of components, only to find out that half of them were useless, you know that not all bargains are what they seem.

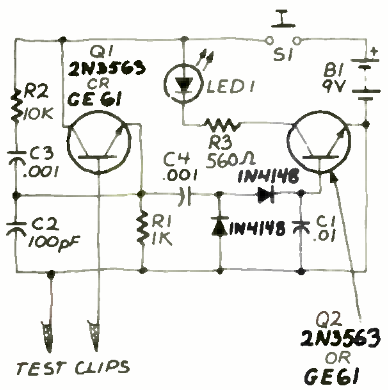


FIG. 1

The ideal solution to that problem, of course, is to find some way to weed out the obviously bad parts before you buy them. The circuit I'll be describing here has proved useful for just that purpose when digging through stacks of crystals, as well as in troubleshooting my equipment. It is small, easy-to-build, and will, at a glance, let you know if a particular crystal will oscillate. Let's look at the circuit shown in Fig. 1.

Transistor Q1, a 2N3563, and its associated components form an oscillator circuit that will oscillate if, and only if, a good crystal is connected to the test clips. The output from the oscillator is then rectified by the two 1N4148 diodes and filtered by C1, a .01-μF capacitor. The positive voltage developed across the capacitor is applied to the base of Q2, another 2N3563, causing it to conduct. When that happens, current flows through LED1, causing it to glow. Since only a good crystal will oscillate, a glowing LED indicates that the crystal is indeed OK. The circuit is powered by a standard nine-volt transistor-radio battery and the SPST pushbutton power-switch is included to prolong battery life.

The circuit is easy to build, with size—for easy portability—the only real consideration. While just about any construction technique will work well, it's easiest to use a small piece of perforated construction-board.

To use the crystal tester, simply connect a crystal to the test leads and close the SPST pushbutton power-switch. If the crystal is OK, the LED will glow brightly. If the LED does not glow, or just glows dimly, the crystal is bad and should not be used.

One note on the intended use for the tester is in order here, however. This tester will check any crystal for oscillation. However, it will not necessarily make the crystal oscillate at the frequency that it is supposed to; so you can't use this tester with a frequency counter to test for that. What the circuit *will* do is give you a way to quickly weed out crystals that are obviously bad, and, after all, that is half the battle.—*Jack Fernandes*

Battery Substituter Has Muscle

IT WOULD SEEM THAT BUILDING A LITTLE power supply to substitute for four flashlight (D cell) batteries would be a simple "handbook" job. Not so! The application in question is powering a widely-sold toy pinball machine.

The problem is that the bright bulb and electromagnetic counter draw an initial surge of about 4 amperes when the steel ball activates a scoring bumper. There are, no doubt, other toys that suffer from the same problem. The pinball machine used up alkaline batteries at a rate that began to cost a significant part of the entire house electrical bill.

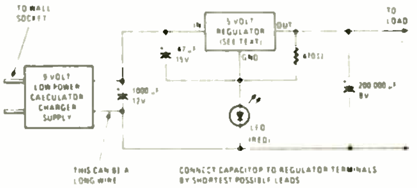
The problem *has* been solved, and I set up the following criteria for the design:

1. The supply should use a *safe* (U-L recognized) line-plug module as calculators or small tape recorders using rechargable batteries do. The idea was not to shock too many of our children, ages 4 through 14.
2. The supply should use an inexpensive and easily available regulator like the National LM340T-5.0 or the 7805-series voltage regulator available from several sources.
3. Despite using the commonly available 5-volt logic regulators, the supply should provide 6.3 to 6.5 volts.

To make the little, 100 mA-rated, calculator/charger supply provide 4-ampere surges required a minor reversal of design philosophy. Not only is the little charger-supply limited in power, but the plastic-packaged regulators that are easily available, are only rated for 1 to 1.5 amperes. Three design tricks provide the solution.

1. Only moderate filtering on the regulator input (see the schematic) is needed, and fast recovery results.
2. *Massive* filtering on the output of the regulator is used (not the usual technique) to supply the surges. The three-terminal IC regulators are stable under these conditions.
3. A LED is inserted in the ground lead of the 5-volt IC regulator. This boosts its output voltage by about 1.5 volts, and provides a nice pilot-light as well.

Parts are not critical. The line-plug supply (transformer is part of plug) that I used had an open-circuit voltage of about 10 volts and could supply a little over 100 mA at 8 volts. [A power converter designed to supply 9 volts to small radios and calculators will do nicely.—*Editor*]



The capacitors are also uncritical since none of the ripple currents are very high. I happened to use two 100,000-microfarad computer-type capacitors on the output because I could get them inexpensively. A number of smaller paralleled capacitors rated at 8 volts or more would certainly work well also. Surplus or junk-box devices would be quite suitable. The IC regulators must have current-limiting to avoid damaging the line-plug type supply with surges.

The battery-eliminator components can be placed wherever you can find the space. The location for the charger is obvious—in the wall receptacle. I distributed the other parts around the pinball machine. The small capacitor and regulator are on a bracket on the back of the machine. The LED is glued into the front panel and the two 100,000-μF capacitors are carefully insulated and then taped to the machine's back legs.—*Peter Lefferts*

Speaker overload protector

MANY OF THE LOWER-PRICED AMPLIFIERS available today do not provide any overload protection for your speakers. The purpose of the circuit shown in Fig. 1 is to remedy that shortcoming.

Relay RY1 is six-volt DPDT unit rated at 3-5 amps. One set of contacts is wired in series with each speaker so that when the relay is *not* energized, the contacts are closed and the circuits between the speakers and the amp are complete.

The input to the circuit is taken from your amplifier's speaker-output terminals or jacks. If the right-channel signal is sufficiently large to charge C1 to a potential that is greater than the breakdown voltage of Q1's emitter, a voltage pulse will appear across R7. Similarly, if the left-channel signal is sufficiently large to charge C2 to a potential that is greater than the breakdown voltage of Q2's emitter, a pulse will appear across R7. The pulse across R7 triggers SCR1, a sensitive gate SCR (I_{GT} < 15 mA, where I_{GT} is the gate trigger-current), that latches in a conducting state and energizes RY1. The action of the relay will interrupt both speaker circuits, and

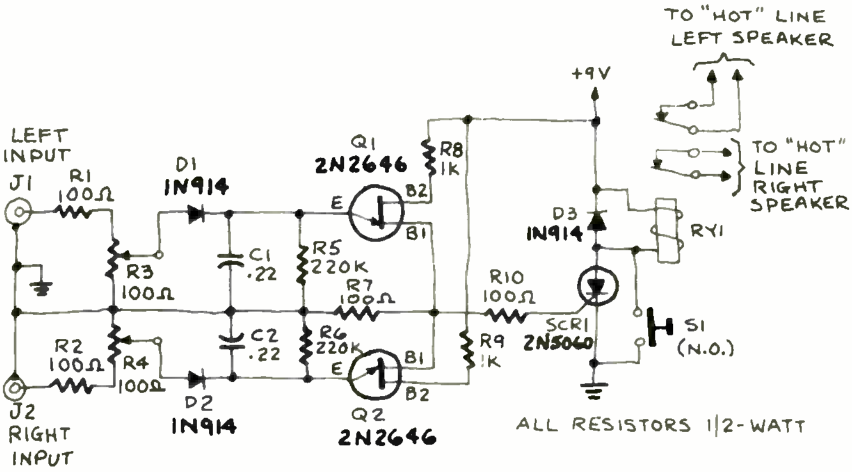


FIG. 1

the resulting silence should alert you to the problem. Cut back the volume on your amplifier, then press and release S1 to reset the circuit and restore normal operation.

The circuit can be adjusted to trip at any level from 15 to 150-watts RMS. To calibrate, deliberately feed an excessive signal to the right input of the speaker protector and adjust R3 until RY1 energizes. Do the same with the left channel, this time adjusting R4. The circuit is now calibrated and ready for use.

—*Willie Ward*

Liquid rosin flux

AFTER I RETIRED, MY INTEREST IN ELECtronics grew tremendously. Partly because of that, I joined the RSVP (*R*etired *S*enior *V*olunteer *P*rogram) and volunteered to help high-school electronics students in their electronics laboratory courses. Recently, the students began to make their own printed-circuit boards for their projects, and the instructor decided that the boards should be tinned (solder plated). What the students would do was to load the board with solder and then sop it up with *Solder Wick*. There had to be a better way to tin a board than that!

One improvement would have been to use some liquid rosin solder flux. However, that was not readily available, and an order would have taken months to fill. A solution was found, though—we made our own liquid flux. It's not very hard to do, and everything you need is shown in Fig. 1.

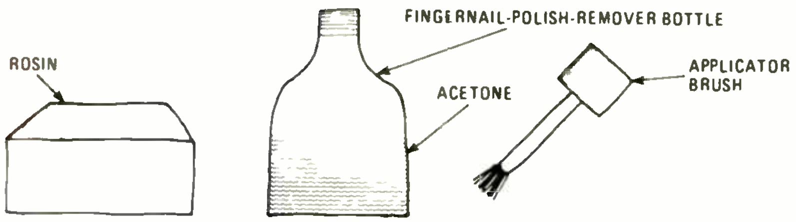


FIG. 1

I knew that the active ingredient in printed-circuit-board cleaners—acetone—dissolves rosin like crazy. So I went to raid my wife's acetone-based fingernail-polish remover—but when I saw the price she paid for it I decided against it. However, I did manage to get my hands on an empty fingernail-polish remover bottle. That bottle was perfect for what I wanted to use it because it came with a handy applicator brush. A little acetone was used to clean both the bottle and the brush.

The next problem was to find the rosin. A violin-repair shop was the source for that. I mashed up a bit of the rosin—a piece about as big as the end of my finger—and coaxed it into the bottle that was half-filled with acetone. It was easy to tell how much rosin to put in—it dissolves very quickly, but little chunks of rosin form at the bottom of the bottle, when you've reached the saturation point. Then, no more will dissolve.

Now I had a little bottle of liquid rosin with its own applicator brush. It's a great way to put rosin flux on printed-circuit boards, to prime connections, to tin stranded wires, and so on. You can probably get by without it; but, believe me, liquid rosin can make many jobs a lot easier.—*Roger F. Sheldon*

Relay Multivibrator

AMONG THE EARLIER MULTIVIBRATORS, one of the simpler models was a device using two relays and one or more capacitors and resistors to control the timing cycle and operating frequency. When it comes to small size and speed, all is in favor of the solid-state electronic multivibrator.

However, from time to time we may need the simplicity of the relay multivibrator. Most circuits shown in literature use the charging of a capacitor to control the timing and one or more resistors to limit the discharge current so it won't damage the relay contacts. The circuit in Fig. 1 was developed around two relays and a single capacitor to perform the same tasks as the more elaborate circuits.

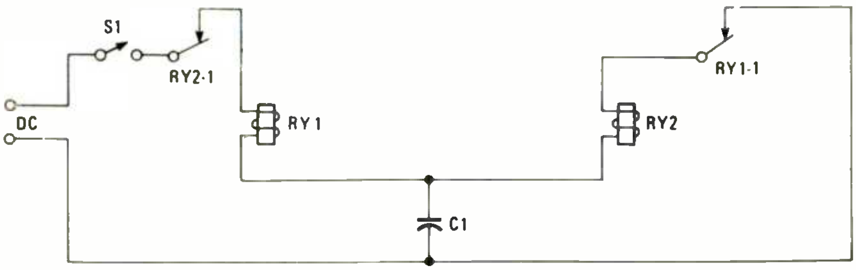


FIG. 1

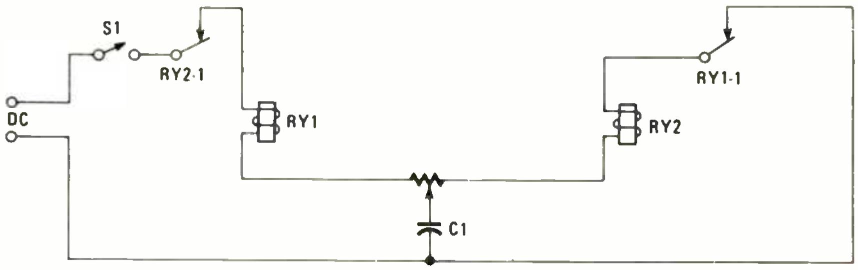


FIG. 2

Circuit operation is as follows: When switch S1 is first closed, the C1 charging current activates relay RY1 and causes its normally closed contacts (RY1-1) to open. When the C1 charging current falls below the hold-in rating of RY1, the relay releases and closes contact RY1-1.

At that moment, the coil of RY2 is connected across C1. The capacitor starts to discharge and the discharge current energizes RY2 and causes contact RY2-1 to open. When the discharge current drops below RY2's hold-in current rating, contact RY2-1 closes to start the cycle anew. The multivibrator will switch back and forth between the relays at a frequency governed by the capacitance of C1, the resistance of the relay coils, the applied voltage, and the hold-in current of the relays. As the relays cycle, switching operations can be carried out as needed by auxiliary contacts on either or both relays.

A potentiometer can be inserted between the relays as in Fig. 2 so you can vary the cycling.—*J. Ofer*

Sliding-tone doorbell

HAVE YOU EVER BEEN STARTLED BY YOUR own doorbell? I have heard some doorbells that are so harsh and startling that they are sure to wreck anyone's nerves. But my doorbell is not of that type—at least not any more.

But if your bell *is* of that type, don't despair. I'll show you a way to prevent your quiet home from being disturbed. You can replace your harsh-sounding, nerve-wracking bell with what I'll call a "mild dose of sound stimulation." When the doorbell is pushed, you'll hear a low tone that will "slide up" to a higher frequency.

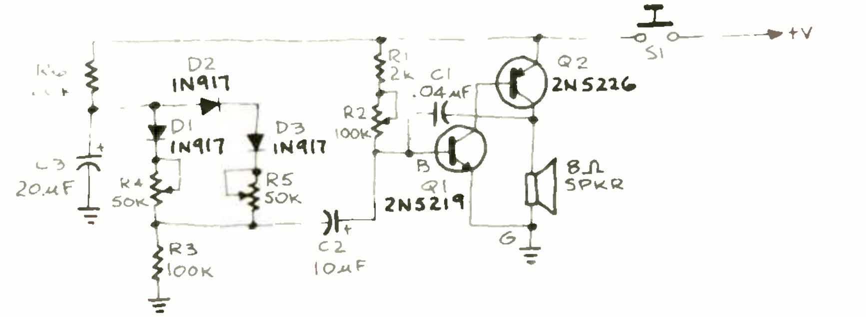


FIG. 1

Figure 1 shows the sliding-tone doorbell circuit. It's made up of two main parts: an AF (*A*udio *F*requency) oscillator and a variable resistance.

The frequency of the AF oscillator is determined by two factors. The first is the value of the coupling capacitor, C1. The second is the value of the resistance connected between the base of Q1 and ground. That resistance, which we'll call R_{BG}, is equal to $(R1 + R2) \parallel R3$.

When either of those two factors increases, the frequency of oscillation will decrease. Thus, whenever R_{BG} or C1 decreases, the frequency will increase.

First, assume that S1 is closed and R2 has been adjusted to produce a pleasant, low-frequency tone. Capacitor C3 will charge through R6 until it reaches such a voltage that will cause diode D1 to conduct. When that happens, the value of R_{BG} is paralleled by R4. Thus, because the total resistance R_{BG} decreases, the output tone slides up in frequency. Capacitor C3 will continue to charge until the voltage across D2 and D3 causes those diodes to conduct. Then R_{BG} is paralleled also by R5, the total resistance again decreases, and the oscillator's frequency again increases.

If you're not satisfied with how the "bell" sounds, there are several things you can do. First, if you want to change the tone variation, feel free to try different values for R2, R4, and R5. And if you want to vary the sliding speed of the tone, then you can try different values of R6.

As with the rest of this easy-to-build circuit, the transistor types are not critical. Feel free to experiment!—*Tseng C. Liao*

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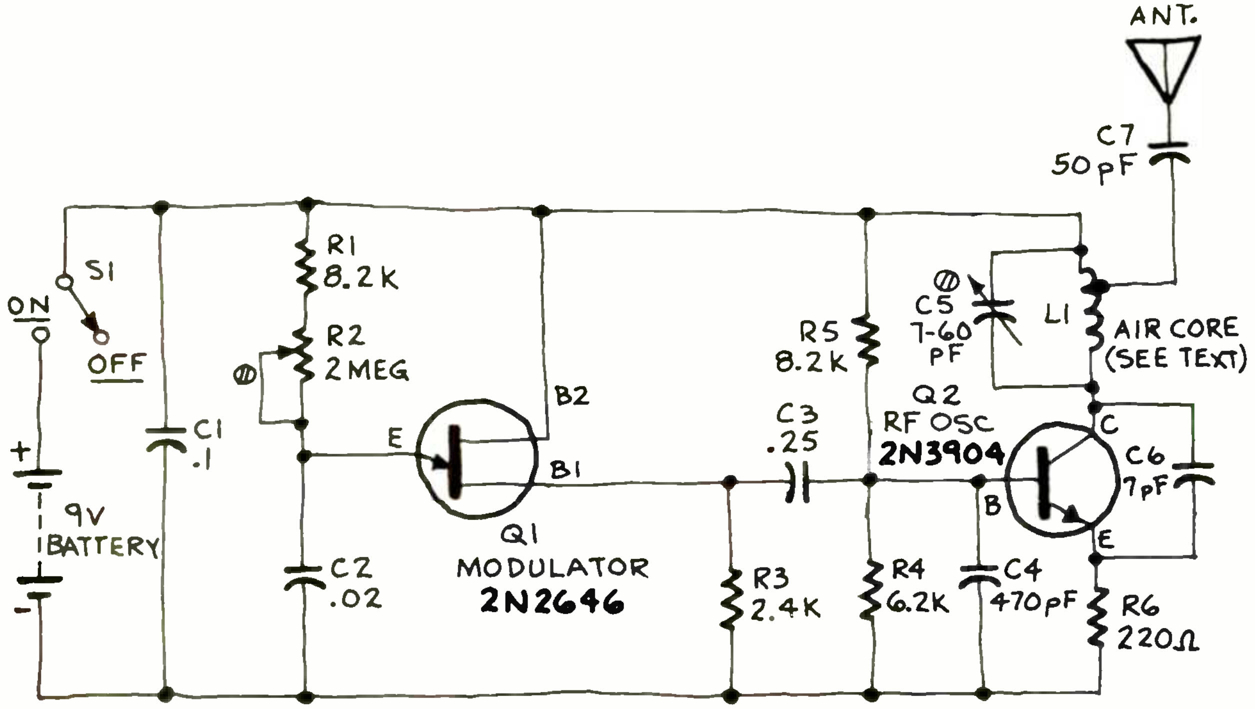

Fig. 1

I'D LIKE TO SHARE WITH YOU A SIMPLE, inexpensive and very useful circuit. Originally designed to generate horizontal bars on a TV screen to aid in vertical-linearity adjustments (test patterns are hard to find these days), the circuit is actually more useful as a RF signal generator that can be used for simple checks of TV and FM-radio RF, IF and AF stages. Its range is about 50 feet with a short whip antenna, but for most applications no antenna is required.

The first section, a tone generator, is made up of a unijunction transistor, Q1, and R1, R2, R3, and C2. Transistor Q1 pulses on and off at a rate determined by the time constant of R1 and R2, together with the capacitance of C2 and the B1–emitter junction of Q1. Trimmer potentiometer R2 determines the frequency of the tone generated and allows a range of approximately 100 Hz to over 5 kHz.

Transistor Q2 is the RF oscillator. Its frequency is set by tuned circuits consisting of L1, C5, C6, and the interelectrode capacitance of Q2. The values shown will give a tuning range of about 55 to 108 MHz. Capacitor C6 provides positive feedback from the emitter to the collector of Q2, for oscillation.

The audio tone generated by Q1 is applied to the base of Q2, causing the collector current to vary at the frequency of the tone, yielding an amplitude-modulated (AM) signal. This, in turn, varies Q2's collector-to-emitter capacitance (which makes up part of the tuned circuit) and causes the output frequency to vary similarly, producing a frequency-modulated (FM) signal, as well. The RF signal is coupled to the antenna through capacitor C7.

Most of the component values are non-critical. Q2 can be almost any silicon RF transistor, such as a 2N3904. (Note: depending on the transistor, the bias-resistor values may have to be changed to obtain stable oscillation.) Capacitor C6 should be a silver mica type; all the others can be ceramic discs or paper. I used 1/2-watt resistors as a compromise between size and physical strength.

Tuning-capacitor C5 is a small trimmer. I used a mica trimmer in my prototype and soldered a short shaft (a machine screw with the head cut off) to its adjustment screw; doing that permitted me to attach a small knob for adjustment purposes.

Coil L1 consists of five turns of number-18 bare wire, close-wound on a piece of 1/4-inch wooden dowel. The length of the winding is about 1/4-inch. One end of capacitor C7 is soldered to the coil one turn away from the nine-volt supply end (refer to Fig. 1) and the other end of the capacitor goes to the antenna. The circuit is easily built on a piece of perforated construction board that can be placed, along with the nine-volt transistor battery, in a small plastic box.

To adjust the vertical height and linearity of a TV set, place the tone transmitter near the set and use R2 to select the number of horizontal bars to be displayed. Once the picture is steady and the bars are sharp, adjust the set's vertical controls so that all the bars are of the same height and are evenly spaced.

Be certain to tune the tone transmitter to an unused TV channel to avoid (illegal) interference with the reception of broadcast stations!

The fundamental tuning range of 55 to 108 MHz covers the lower TV channels and the FM broadcast band, but harmonics can still be detected—although more weakly—on the upper-VHF and UHF channels. The fact that both AM and FM signals are generated makes it possible to use this transmitter to check almost any receiver within its frequency range. A TV set's sound section (discriminator) will reject the AM portion of the signal, while its video section will respond to it. Similarly, the TV sound section, and FM receivers, will respond to the FM signal produced.—*Robert M. Laskie*

Boiler Control

THE PURPOSE OF THIS CIRCUIT IS TO CONtrol the water temperature in a hot-water heating system. What it does is to lower the boiler temperature as the outside air temperature increases. For example, if the outside temperature is 0 (Fahrenheit), the boiler temperature would be 180°; if the outside temperature is 50°, the boiler temperature would be 140°, and so on. The result is a savings in fuel consumption.

The circuit is shown in Fig. 1. The op-amp—almost any common type will do—is used as a comparator. Thermister TH2 and R2 form a voltage divider that supplies a reference voltage to the op-amp's inverting input. Thermistor TH2 is placed outdoors, and the values of TH2 and R2 should be chosen so that when the outside temperature is 25°, the resistance of the thermistor and resistor are equal.

Resistor R1 and thermistor TH1 make up a voltage divider that supplies a voltage to the op-amp's non-inverting input. Thermistor TH1 is placed inside the boiler and the values of TH1 and R1 should be chosen so that when the boiler's temperature is 160°, their resistances are equal.

The output of the op-amp controls Q1, which is configured as a transistor switch. When the logic output of the op-amp is high, Q1 is turned on, energizing relay RY1. The relay's contacts should be wired so that the boiler's heat supply is turned on when the relay is *de-energized* and turned off when the relay is energized. An indicator, LED1, glows when the transistor conducts (Q1 is turned on), informing you that the boiler's heat supply is turned off (relay energized).

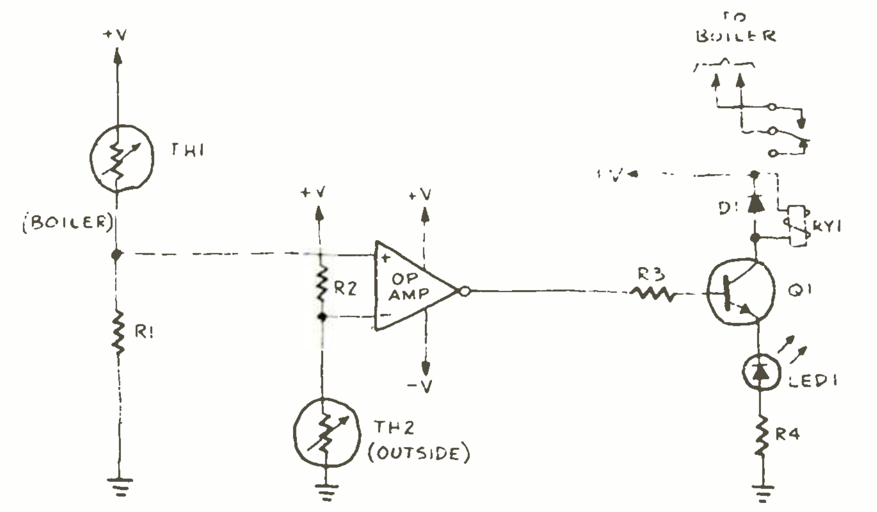

FIG. 1

Circuit operation

As the outside temperature increases, the resistance of TH2 increases. The higher the resistance of TH2, the higher the voltage applied to the inverting input of the op-amp. But as the temperature of the boiler increases, and the resistance of TH1 goes up, the voltage applied to the non-inverting input of the op-amp decreases.

Perhaps the best way to see how that works is with an example. If the temperature in the boiler is 160° and the outside temperature is 25°, the voltages at the non-inverting and inverting inputs of the op-amp are equal. As the boiler heats up, the voltage at the non-inverting input becomes higher than the voltage at the inverting input. That, of course, causes the op-amp's logic output to go high, energizing the relay. When the relay is energized, the boiler's heat supply is turned-off.

As the boiler cools off, and the temperature drops below 160°, the logic output of the op-amp goes low, de-energizing the relay, and turning on the boiler's heat supply. The boiler's on/off point is determined by the voltage at the op-amp's inverting input, which in turn is determined by the outside temperature.—*Scott Busey*

Plant Water Gauge

THIS PLANT WATER GAUGE CAN EASILY BE constructed on a small piece of perforated construction board. Its case is made from a piece of Styrofoam with a section carved out to hold the nine-volt battery, and a small recess is made into which the underside of the board is pressed. The probes are stuck right through the center of the foam and glued in.

Assemble the gauge following the schematic in Fig. 1 and the drawing in Fig. 2. Be sure to tin the probes with solder to keep them from corroding.

To calibrate the gauge, connect the battery and press the probes gently into a pot containing a plant that is just on the verge of needing water (stick it in so that only an inch of the probe is left visible at the top). Turn the potentiometer until the "OK" LED lights and then turn it back to the point where that LED goes out and the "W," or "Water," LED just comes on. The device should now be properly adjusted.

Use this gauge anywhere for indoor plants and you will find it very useful in determining when to water and in preventing overwatering, since it reaches much farther down into the soil than you possibly can with your own fingers. *Bob Mostafapour*

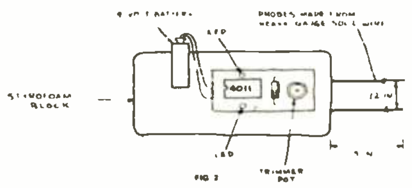

FIG. 2

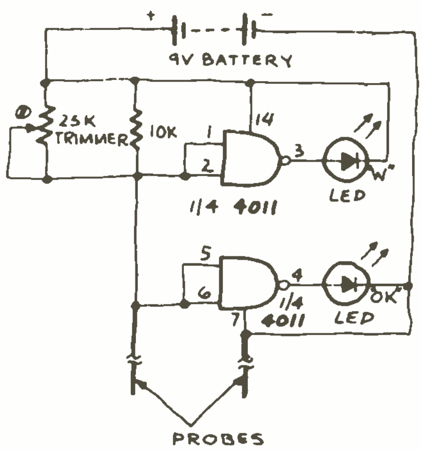

FIG. 1

FREQUENCY COUNTER

continued from page 154

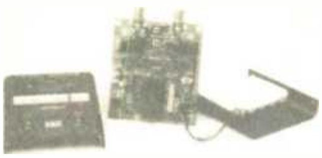

FIG. 8—ONCE INSTALLED IN ITS CASE, the counter makes a neat, compact, and easily transportable test instrument.

pins, check for alignment, correct if necessary, and only then solder the remaining pins. A small piece of double-sided foam tape should be placed under the crystal to insulate its case and to provide a shock mount. Finally, install the electrolytic capacitors, C12 and C13, on the board's rear.

Now clean the board and check it thoroughly for solder shorts and opens. When you're satisfied that the board is in good shape, install the IC's. Your board should now appear as in Fig. 7.

Set the SENSITIVITY switch to NORM and the GATE switch to FAST. With the RANGE switch in either position, apply power. The GATE LED should blink and the display should indicate .000 with leading digits blanked. Move the GATE switch to the SLOW position. The display should now read .0000, and the GATE LED should blink at a slower rate. Now move the SENSITIVITY switch to HIGH; the display should show a random, changing count on both ranges.

If the display is dim or blank, remove power, and make sure all IC's are installed correctly. If so, check the orientation of all the diodes and electrolytic capacitors. Re-check the PC board for shorts and opens if necessary. Finally, your power source may be weak or dead, or a switch may be bad.

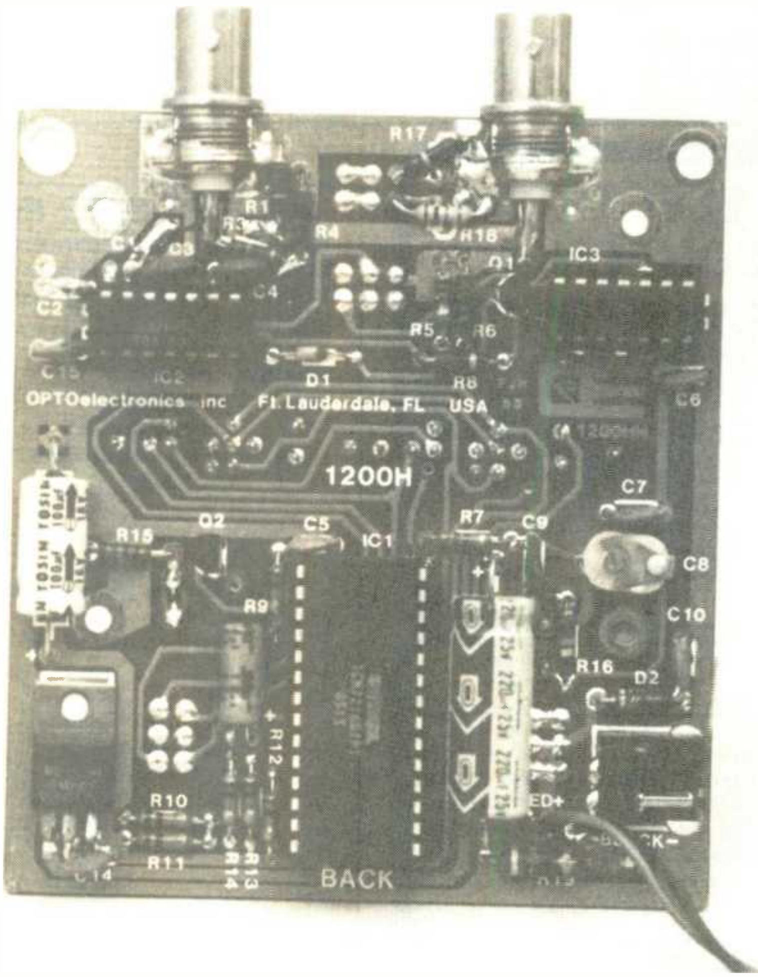

FIG. 7—ONCE ALL COMPONENTS are in place, clean the board and check your work for any shorts or opens.

Calibration and final assembly

To calibrate the counter, connect a stable signal of known frequency to the proper input jack, and then adjust trimmer capacitor C8 for proper display. Use the highest frequency you can and the SLOW gate time in order to get maximum resolution and accuracy.

Remember that a counter's accuracy is specified in PPM (*P*arts *P*er *M*illion), and if a reading is 1 PPM high at one frequency, the counter will read 1 PPM high at all frequencies. At 1 kHz a 100 PPM error would, in many applications, be insignificant. But a 100 PPM error at 10 MHz would be quite significant. So calibrate the counter carefully!

When it is calibrated, you can mount it in its case, see Fig. 8. If you use the case mentioned in the Parts List, the PC board just slips into it. The BNC connectors and the power jack should line up with the holes in the case perfectly. Drop a red plastic filter over the displays and then screw the case together. You're ready to start using your 1.2-GHz frequency counter now!

Usage hints

Keep in mind that the counter requires only a few millivolts to make an accurate reading—seldom more than about 50 mV. Inexperienced users commonly overdrive the frequency counter—and that could cause erroneous readings or circuit damage. Signals of several volts or more should be loosely coupled by a small capacitor or picked up inductively by a loop-type probe or antenna. When connecting the frequency counter directly to a circuit, use a 10K series resistor to reduce ringing and to lighten the load on the test circuit. Other than following those simple precautions, you should have no trouble using the counter.

Since the the price-to-performance ratio of this circuit is so good, you may want to install one permanently in a piece of equipment such as a ham rig or a commercial radio transmitter. That way you could have a continuous indication of output frequency, and any drift could be corrected before it caused interference to stations transmitting on nearby frequencies.

Or, for a very handy and versatile piece of test gear, you could combine our circuit with an inexpensive function generator in a single cabinet. Also, it would be easy to adapt our circuit for automotive or marine use. If you do, be sure to wire a ¼- to ½-amp fuse in series with the counter's power input line.

As you can see, our frequency counter is so inexpensive and so easily adaptable that new applications for it seem to suggest themselves! You'd better start building several—you'll use 'em before you know it! **R-E**

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CIRCLE 93 ON FREE INFORMATION CARD

DEALER'S BOOKLET, the *TVRO Service Dealer's Master Receiver List and Filter Connection Guide*, describes filtering TI (Terrestrial Interference) in over 500 different receivers.

The booklet discusses how to identify whether a receiver is standard or block conversion, its IF frequency, connector type, and whether it's synthesized or AFC (Automatic Frequency Control) driven.

Based on characteristics identified, the best filter to solve the interference problem is recommended. Two other filters are also listed: a second-best, and one for weak signal situations. Diagrams show where the filters should be installed in the system. Descriptions of the filters are also included.

The *TVRO Service Dealer's Master Receiver List and Filter Connection Guide*, is priced at $9.95.—**Microwave Filter Company, Inc.**, 6743 Kinne Street, East Syracuse, NY 13057.

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TEST-INSTRUMENTS CATALOG, *Nicolet Test Instruments*, is letter-size, 64 pages on coated stock with both color and black-and white illustrations and specifications. Two new products are included for the first time: The *NIC-370* signal averager, and the *DJ*—a floppy-disk-drive tester.

Also included in the catalog are digital oscilloscopes, logic analyzers, in-circuit emulators, and accessories.—Nicolet Instrument Corp., Nicolet Test Instrument Div., Bldg 2, P.O. Box 4288, Madison, WI 53711.

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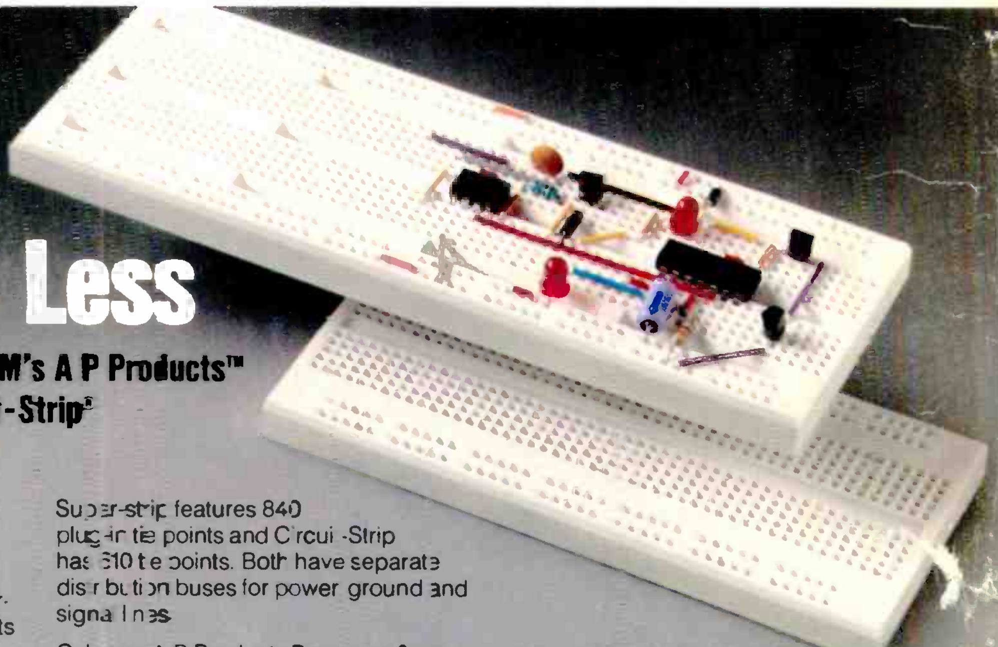

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