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COVER PHOTO BY JAY BRENNER STUDIO

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Tools routinely used in the pursuit of the electronics hobby include a variety of screwdrivers, longnose pliers, diagonal wire cutters, and a soldering tool (a Wahl "Iso-Tip" cordless soldering iron is shown). This minimal lineup will suffice for kit and simple project building but is usually supplemented by special-purpose tools for building complex projects from scratch.
SUCCESSFUL SOLDERING

Helpful tips on materials, tools, and techniques

BY JOHN D. BORNEMAN

In electronics, the basic goal of soldering is to electrically and mechanically join two circuit components. For this connection to be reliable, the solder must adhere to or “wet” the mating surfaces of the components being joined. The wetting of solder to a base metal is similar to the action of water spilled on a smooth surface: if the surface is clean and free of dirt, wax and oils, the water will wet and spread evenly over it; if the surface is waxed, the water balls up.

Most manufacturers of electronic components do a good job of making their products of easily solderable material or providing a clean solderable coating. Copper, copper-clad steel, or nickel-steel are some of the common base metals used in the leads of resistors, capacitors, integrated circuits, etc., and they may be coated with silver, tin, tin-lead, or gold to improve solderability. Greases, oils, dirt, and oxides are the principal sources of contamination that prevent good solder wetting despite the original surface. Also, aging deteriorates the surface and inhibits solder wetting by the formation of oxide films.

Solder Alloys and Fluxes. Technically, soldering is the joining of two parts with a metal alloy having a melting point below 800°F. Various solder alloys include combinations of tin, lead, antimony, silver, indium, and bismuth; however, the most common combination is tin and lead. Tin-lead solders range from pure tin to pure lead and include all proportions in between. For plumbing, alloys of 10% tin and 90% lead (10/
90 solder) are commonly used. In electrical soldering, the alloy mix is usually 60% tin and 40% lead (60/40).

Characteristics of alloys of tin and lead are plotted against temperature in Fig.1. This graph, referred to as a phase diagram, allows one to see that only a 63/37 alloy has a eutectic point—that is, a single melting point. All other alloys start melting at one temperature, move through a "pasty" or semisolid stage, and then become liquid at a higher temperature. Any physical movement of the components being soldered while the solder is in the "pasty" range will result in a "cold" joint. Such a joint appears grainy and dull, and is mechanically weaker, thus less reliable. Therefore, 63/37 or 60/40 solder is commonly used in electronics since they do not remain long in a "pasty" phase. However, a 50/50 alloy can be used if proper care is taken.

An often-ignored aspect of soldering is the flux. The word flux comes from the Latin root "fluere" meaning "to flow." Soldering flux, which is usually included in the solder as a central core, or separately in liquid or paste form, helps the solder alloy flow around the connection. Flux also cleans the component leads of oxides and films, and allows the solder to wet their surfaces.

Chemically, flux is either acid or rosin based. Always use rosin flux in electronic soldering since the acid may cause corrosion. "Activated" rosin or "RA" flux produces better cleaning and flowing properties than the popular mildly activated fluxes (RMA), and they are noncorrosive.

**Equipment.** The tools required to solder electrical connections are: a good soldering iron and a supply of replaceable tips, long-nose pliers for holding parts or bending leads (or as a heat sink for temperature-sensitive components), and desoldering braid (or a suction desoldering tool).

There are basically two types of soldering instruments—the "gun" and the "iron," although most people use these descriptions interchangeably. In essence, a soldering "gun" is a pistol-shaped device consisting of a transformer forming the bulk of the "gun," with the secondary winding extending out to form the replaceable tip. Usually, soldering guns come with high wattages, in most cases too high for use with pc foil patterns. Such guns also generate a high magnetic field around the tip that can de-gauss any magnetically sensitive devices close to it. Using a gun may produce too high a heat on the foil pattern so that the cement that secures the copper foil pattern to the substrate is weakened and the foil separates from the printed circuit board.

The "iron" is often called a "pencil iron" because it resembles a thick pencil that is held in the fingers. These tools feature interchangeable (usually screw-on) tips having various shapes—each for its own purpose. Their wattages are usually low enough to be safely used on pc boards. The latest version of the pencil iron is the low-wattage self-contained rechargeable type that can be used remote from the ac line.

Soldering irons are specified primarily by wattage as shown in the table. Wattage represents the amount of heat capacity available at the iron tip. Irons of all wattages usually run at about the same tip temperature, but a lower-wattage iron will cool faster during soldering. The recommended wattages given in the table are to be used as general guidelines only. Slight variations may give perfectly good performance, depending on the particular soldering situation. A higher-wattage iron is more likely to damage heat-sensitive components. If static-sensitive components are to be soldered, i.e. many MOS devices, be sure the iron has a grounded plug. Soldering irons can produce static voltage spikes that will destroy many integrated circuit components, so a grounded tip is a wise safety measure.

Tips are usually selected by preference. Each type and shape has its place and purpose, but the commonly used pointed, conical type is the most versatile and convenient. Desoldering equipment is always useful even for experienced solderers. Both braid and suction devices are effective and, again, operator preference is the best guide. If you elect to use a suction desoldering tool, pay close attention to the distance and velocity that the "piston" requires. It is very easy to get a black eye, or have glasses damaged, when using those devices.

**Soldering Techniques.** The best technique can be outlined simply. First, make sure that the tip of the iron is at operating temperature, and is clean. Then touch the heated tip to the connection, preferably on the part having the larger mass (Fig. 2). The solder should not be brought to the joint until the
metals being joined have become hot enough to melt it. How long this takes is quickly learned after a few trials. The flux-cored solder is then brought to the joint and placed at the junction of the two parts. When the solder has melted and flowed into a smooth-contoured fillet, remove the solder. Keep the tip on the joint for a few seconds, then remove it. Do not disturb the newly made connection until it has had time to solidify. A good solder joint will be shiny (Fig. 3). Disturbing the joint before it has solidified may produce a “cold” joint.

**Problem Solving.**

To Avoid Cold Joints. Even when you know that the parts should not be moved while the solder joint is cooling, it is sometimes difficult to find enough hands to hold a soldering iron, solder, circuit board, and the part being attached. In this case, a small vise or a surgeon’s hemostat may be used to hold the board and parts. If you are using rosin flux in liquid or paste form, another method is possible. Using long-nose pliers, hold the part to the circuit board. Apply flux to the pieces being soldered and take up the soldering iron. Touch the iron to a length of solder, creating a ball on the tip. Touch the tip to the connection and hold it there until the fillet is formed. This will create a good joint and free your hands to hold the parts.

To Get Good Solder Wetting. Clean the parts well with isopropyl alcohol to remove greases and oils, and use a 10% solution of hydrochloric acid (HCl) to remove the oxides. Fine steel wool may be used on foil patterns to remove oxide films. These chemicals should be available from any drugstore, but remember to ask about any handling precautions before using them. Note that extra liquid flux can also help in soldering contaminated parts.

To Make Solder Flow. Be sure the soldering iron is providing enough heat, with the iron tip on tight and the proper wattage being used. Also be sure enough flux has reached the component leads and that it is not necessary to add extra liquid or past flux. Do not keep the iron on the joint or continue adding solder if a connection is not made after two trials. This will only damage the components or the circuit board.

**To Solder ICs and Other Small Components.** Use only a low-wattage iron and sharp tip to avoid excess heat. Also, use 0.031-inch diameter solder to help control the amount of solder deposited. Provide a heat sink by using long-nose pliers to grasp the lead between the component package and the portion to be soldered.

After completely soldering a PC board, an inspection of the soldered joints is suggested. A toenail clipper can be used to trim any lead ends so they don’t protrude too far from the solder. To help in the inspection, a bright spotlight and low-power lens can be used to examine each joint. A sharp tool can clear away dross, solder bridges, or anything that looks suspicious between solder pads, and a toothbrush can be used to clean the solder joint. To make sure that all joints are checked, a drop of red nail polish can be placed on each after inspection. A minute spent checking a board can save an hour of troubleshooting later on.

Another problem can arise when a plastic capacitor appears to be “soldered” in place, but is not making an electrical connection. This often happens when a small “sleeve” of nonconductive plastic extends from the capacitor body slightly down each lead. The solder will hold the plastic to the pad, but an electrical connection may not result. Use long-nose pliers to break away the unwanted plastic.

Since your fingers may be dirty or oily, handle parts and circuit boards as little as possible. If there is any question of oily spots on a part, clean it using isopropyl alcohol or fine steel wool. If you use steel wool, use lint-free cloth to remove all vestiges of the wool from the parts or board.

**To Summarize:**

1. Use clean new parts and circuit boards.
2. Use 60/40 or 50/50 tin-lead alloy solder with an activated rosin core. Liquid or paste rosin flux may be used to improve wetting when necessary.
3. Use the proper wattage soldering iron based on the amount of soldering to be done and the type of components being soldered.
4. Use the proper soldering sequence—tip to parts, solder to parts—solder away from parts—tip away from parts.
5. Use patience.
6. Practice.
When difficulties occur in loading data from a cassette tape into a microcomputer, it is usually because the commercial tapes being used are poorly duplicated. This is further compounded by the quality of the tape itself and even the inadequacies of home tape machines.

In the case of the popular Radio Shack TRS-80, a narrow tape level setting range and fussy timing requirements exacerbate the problem. Though some peak-reading meters enable one to set the proper level quickly, they do not generally correct for poorly shaped pulses or timing jitter, both of which are major obstacles to successful loads. The Tape Regenerator project described here has been designed to obviate this problem. The Regenerator is an advanced breed of tape-conditioning device. It is for use with TRS-80 Level II BASIC and machine-language (SYSTEM) programs. Unlike other commercially available conditioners, it uses both hardware and software. As a result, the computer itself is used for curing timing problems.

This permits poorly timed backup copies to be made on a second recorder which, without internal retiming, would produce backup copies that retain or worsen timing jitter.

**How It Works.** The ideal signal waveform and typical “good” and “poor” waveforms found on commercial copies of Level II programs are shown in Fig. 1. As shown in Fig. 1C, superimposed noise, power-line hum, amplitude distortion, and ringing and displacement of the data pulse relative to the clock pulse (timing jitter) can make it likely that the computer will lose bits. And a single lost bit, of course, makes the entire program useless.

Once a BASIC program has been properly loaded, a back-up copy of it can be made using the CSAVE command. Similarly, a backup copy of a machine language (SYSTEM) program can be
# MICROPROCESSOR COMPONENTS

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Description</th>
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<tr>
<td>CD4015</td>
<td>CMOS 4015 40pin</td>
<td>$0.002</td>
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<td>74LS00</td>
<td>CMOS 00 quad 2-input NAND gate</td>
<td>$0.16</td>
</tr>
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<td>74LS08</td>
<td>CMOS 08 quad 2-input OR gate</td>
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<td>74LS24</td>
<td>CMOS 24 2-input NOR gate</td>
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<td>CMOS 32 quad 2-input AND gate</td>
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<tr>
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<td>CMOS 54 2-input XOR gate</td>
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<td>74LS57</td>
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<td>74LS10</td>
<td>CMOS 10 2-input OR-AND gate</td>
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<td>74LS12</td>
<td>CMOS 12 2-input OR gate</td>
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<td>74LS13</td>
<td>CMOS 13 2-input AND gate</td>
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# DYNAMIC RAMS

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<tr>
<td>2114</td>
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<td>2126</td>
<td>CMOS 2126 2K x 8 RAM</td>
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<td>2136</td>
<td>CMOS 2136 8K x 8 RAM</td>
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<td>2164</td>
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# STATIC RAMS

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<tr>
<td>74LS373</td>
<td>CMOS 373 8-bit AND gate</td>
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<tr>
<td>74LS273</td>
<td>CMOS 273 8-bit OR gate</td>
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<tr>
<td>74LS274</td>
<td>CMOS 274 8-bit XOR gate</td>
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# PROMS

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<td>2716</td>
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<td>2764</td>
<td>CMOS 2764 16K x 1 RAM</td>
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    - 1¢
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    - 1¢
  - 32 pin T2.5
    - 1¢

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made with a monitor program, e.g. Radio Shack T-BUG. However, the original program must be readable and short enough to fit into memory without overwriting a monitor program.

The Tape Regenerator and associated program, DUB3 (see Table), overcome these limitations by reshaping and retiming the pulses to produce new tape that the TRS-80 can easily read.

Multiple-segment programs (some programs feature a separate loader) or several programs on a single tape pose no problems for the Regenerator, either. Operating on one pair of clock/data pulses at a time without storing the whole program in RAM as monitor programs do, the Regenerator allows even a TRS-80 computer with only 4K of RAM to back-up copies of arbitrarily large programs and handle tapes containing multiple programs in a single cassette pass.

To test the soundness of the Tape Regenerator design, the author created five generations of the same program and found that the fifth-generation tape would load as easily as the original.

**Circuit Description.** The circuit shown in Fig. 2 reshapes the clock and data pulses received from the tape recorder and feeds them to the computer. Audio transformer \( T1 \) provides dc isolation between the tape recorder and the Regenerator circuit. Switch \( S1 \) and diodes \( D1 \) and \( D2 \) allow selection of the “better” half of the pulse (see Control Adjustments later on), while zener diode \( D3 \) and transistor \( Q1 \) further shape the incoming signal. One OR gate in \( IC1 \) decodes the IN command from the computer (via the \( Pl \) connector) indicating that the computer is ready to accept data. When this command occurs, \( IC1 \) (pin 8) activates \( IC2 \) (via pin 15) to allow the amplified tape recorder signals to pass via the connector \( Pl \) expansion port to the computer data bus. Indicator \( LED2 \) and optional meter \( M1 \) indicate that the tape recorder is sending data at the proper level, and \( LED3 \) glows when regenerating program DUB3 is up and running. If no back-up copies are required, \( J2 \) provides a “quick-and-dirty” direct output to the TRS-80 via the tape recorder plug. The signal at this point is not retimed and is only partially reshaped. This limited processing may make a tape readable.

Power for the circuit (Fig. 3) is provided by transformer \( T2 \), in conjunction with voltage regulator \( IC3 \), bridge circuit \( RECT1 \), and capacitors \( C1 \) and \( C2 \). Power-on is indicated by \( LED1 \).

---

**PARTS LIST**

- **C1**—200-µF electrolytic
- **C2,C3**—0.1-µF disc capacitor
- **D1,D2**—1N914 silicon diode
- **IC1**—74LS32 quad OR gate
- **IC2**—74LS368 hex tri-state buffer
- **IC3**—7805 +5V regulator
- **LED1,LED2,LED3**—Red light-emitting diode
- **M1**—1-mA meter (Radio Shack No. 270-1752 or similar)
- **P1**—2 × 20 edge connector on 0.1” centers to fit expansion port on TRS-80 keyboard or expansion interface
- **Q1**—Npn transistor (Radio Shack No. 276-2014 or similar)
- **R1,R3,R5**—270-ohm, ½-W resistor
- **R2**—10,000-ohm, ½-W resistor
- **R4,R6**—820-ohm, ½-W resistor (optional)
- **RECT1**—50-V, 1-A bridge rectifier
- **S1,S2**—SPdt switch
- **T1**—Audio transformer (Radio Shack No. 273-1380 or similar)
- **T2**—12-V transformer (Radio Shack No. 273-1385 or similar)
- **Misc.**—Suitable enclosure; 14- and 16-pin DIP IC sockets; line cord; solder; etc.

**Note:** An etched, drilled, or silk-screened printed-circuit board listing of DUB3 program in BASIC to allow POKEing into memory are available for $11.95 (plus 6% sales tax for New Jersey residents) from C&R Electronics, P.O. Box 217, Holmdel, NJ 07733.
Construction. The circuit can be assembled on a small pc board, or Wire Wrap techniques can be used. Keep all leads as short as possible. As only four contacts are used on the 40-pin TRS-80 connector, the remaining pins can be expanded with a screwdriver to make plug insertion easier. Before turning on the power, recheck all wiring, especially the leads to the computer expansion port.

Control Adjustments. To properly read a poorly recorded tape, polarity switch SJ on the Tape Regenerator and the volume control of the tape recorder must be set. These settings will vary from tape to tape. However, back-up tapes made by the Tape Regenerator or CSAVE command should all work with the same settings.

To determine the proper settings for an unknown tape, observe LED2 and millimeter MI, or connect a scope to TP1. Play the tape at medium setting of the tape recorder volume control. Flip polarity switch SJ and leave it in the position corresponding to a stronger signal, as evidenced by a brighter LED, higher reading on the meter, or a cleaner pulse display on the scope. Optimum setting of the recorder playback level is found by advancing the volume control until LED2 glows brightly, then backing off slightly. If optional meter M1 is included in the circuit (see Fig. 2), adjust the volume control for a reading between 0.5 and 0.6 mA. As a final alternative, connect an oscilloscope to TP1 and adjust the control for the cleanest, widest pulses you can.

Regenerator Program DUB3. The reshaping and retiming of Level II clock and data pulses as received via the PI connector is performed by the DUB3 program. After clearing the screen and displaying a message, the DUB3 program searches for a clock pulse. When one is found, the time interval to a second pulse is checked to make sure that the first was not a spurious transient. When the clock pulse is confirmed, it is output after a 200-µs delay using subroutine OUTPUT. This subroutine produces a clean signal lasting 300 µs, as shown in Fig. 1A. A search for the data pulse now begins. The delay of 500 µs excludes any residual ringing from the preceding clock pulse. If no data pulse is found during the following 700-µs window, a search for the next clock pulse begins. If a data pulse is detected in the win-

---

**Fig. 3.** The power supply is a simple rectified regulator circuit as shown here.

**Fig. 4.** Timing diagram of DUB3 program. Input at TP1 is at top. Below is output from computer.

**Fig. 5.** Electrical interconnection of the Tape Regenerator to the TRS-80 computer and two tape recorders.
TABLE—LISTING OF DUB3 PROGRAM

00100 PORT EQU 00H
00110 CENTER EQU 04H
00120 HIGH EQU 05H
00130 LOW EQU 06H
00140 DL100 EQU 0CH
00150 DL150 EQU 12H
00160 LEN1 EQU 14H
00170 DL200 EQU 1AH
00180 DL700 EQU 22H
00190 LEN2 EQU 22H
00200 CASS EQU 0FFH
00210 CLS EQU 0109H
00220 LINE1 EQU 3DD6H
00230 LINE2 EQU 3E0FH
00240 ORG 4A00H
00250 DUB3 CALL CLS ;CLEAR SCREEN
00260 LD HL,TAB1 ;DISPLAY LINE1
00270 LD DE,LN1
00280 LD BC,LEN1
00290 LD LDIR
00300 LD HL,TAB2 ;DISPLAY LINE2
00310 LD DE,LN2
00320 LD BC,LEN2
00330 LD LDIR
00340 START LD B,DL100 ;100 MICS DELAY
00350 DEL0 DJNZ DEL0
00360 SRCHC IN A,(PORT) ;START CLOCK PULSE SEARCH
00370 RRA
00380 JR NC,SRCCHC ;CLOCK PULSE FOUND?
00390 IN A,(PORT) ;YES, TRANSIENT ONLY?
00400 RRA
00410 JR NC,SRCCHC,YES, KEEP SEARCHING
00420 RRA
00430 DEL1 DJNZ DEL1
00440 CALL OUTPUT ;PUT OUT CLOCK PULSE
00450 LD B,DL700 ;START 700 MICS READ WINDOW
00460 SRCHD IN A,(PORT) ;SEARCH FOR DATA PULSE
00470 RRA
00480 JR C,FOUND1 ;FOUND?
00490 DJNZ SRCHD ;NO, WINDOW TIMED OUT?
00500 JR START ;YES, SEARCH FOR CLOCK PULSE
00510 FOUND1 IN A,(PORT) ;TRANSIENT ONLY?
00520 RRA
00530 JR C,FOUND2 ;NO
00540 DJNZ SRCHD ;YES, WINDOW TIMED OUT?
00550 JR START ;YES, SEARCH FOR CLOCK PULSE
00560 IN A,(PORT) ;DATA PULSE FOUND
00570 FOUND2 INC IX ;WASTE 10 CYCLES
00580 BIT 3,(HL) ;WASTE 12 CYCLES
00590 DJNZ FOUND2 ;WINDOW TIMED OUT?
00600 CALL OUTPUT ;YES, PUT DATA OUTPUT PULSE
00610 JR START ;SEARCH FOR CLOCK PULSE
00620 OUTPUT LD A, HIGH ;PULSE OUTPUT
00630 OUT (CASS),A ;PULSE HIGH
00640 LD B,DL150 ;150 MICS DELAY
00650 DEL2 DJNZ DEL2
00660 LD A,LOW
00670 OUT (CASS),A ;PULSE LOW
00680 LD B,DL150 ;150 MICS DELAY
00690 DEL3 DJNZ DEL3
00700 LD A,CENTER
00710 OUT (CASS),A ;RESTORE TO CENTER
00720 RET
00730 TAB1 DEFM 'TAPE BACK-UP PROGRAM'
00740 TAB2 DEFM 'COPYRIGHT (C) 1980 CASS R. LEWART'
00750 END DUB3

dow, it is checked again to exclude a transient and, if confirmed, is output at the end of the 1-millisecond interval that started at the beginning of the preceding clock pulse (Fig. 4).

A data pulse appearing at any time between 500 μs and 1.2 ms after a clock pulse is correctly retimed to occur exactly 1 ms after the clock pulse. After a 100-μs delay, the program continues with the search for the next clock pulse. The DUB3 program can be loaded using the Radio Shack Editor/Assembler or by keying in the Z80 instructions. For a BASIC version of the DUB3 program that will POKE the instructions into memory, see the Parts List.

Operating Instructions. Electrical interconnection between the Tape Regenerator, both tape recorders, and the computer is shown in Fig. 5. Always turn off the computer and Regenerator when plugging or unplugging the 40-pin connector at the rear of the TRS-80 keyboard.

If you have the Expansion Interface connected to your computer, use the expansion port on the left side of the Expansion Interface instead of the expansion port at the rear of the keyboard. When power is applied to the computer and Tape Regenerator, LED1 should glow and the MEMORY SIZE? prompt should appear on the video monitor. If the prompt does not appear, check connections, particularly the 40-pin connector, between the Tape Regenerator and the TRS-80. Load and run the DUB3 program. Indicator LED3 (PGM ON) should glow as long as DUB3 is running. The program is in an infinite loop and will run until you press the RESET button on the rear of the TRS-80 or turn off power to the computer.

For initial adjustment, start reading tape from tape recorder 1 and set polarity switch S1 and the tape recorder volume control as explained under Control Adjustments.

Rewind tape recorder 1 and start it in the play mode while starting tape recorder 2 in the record mode with a clean tape. When the program on tape recorder 1 is finished, LED2 (VOL) will extinguish and meter M1 will indicate close to zero. This is the signal for you to turn off both tape recorders. You can continue with as many tapes as desired. When finished, open S2 to turn off power to the Tape Regenerator, press the RESET button to return the TRS-80 to BASIC, or turn off the computer. The 40-pin connector (P1) can be left permanently plugged into the expansion port, as it does not interfere with normal computer operation. If the pulse amplitude on the original tape is very unsteady or the pulses are imbedded in noise, regenerating the tape may not be possible.
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Two Projects for Outdoor Use

A BATTERY-OPERATED FLUORESCENT LAMP

Portable, high-efficiency light source draws current from a vehicle's 12-volt storage battery, but leaves plenty of charge for engine starting.

BY LAWRENCE M. WALDEN

The recreational vehicle is becoming more and more popular with campers who want a "home away from home." In such cases, the vehicle's 12-volt battery supply provides a convenient source of power for lighting around the camp. This is very handy, of course; but, for the amount of light they deliver, 12-volt incandescent lamps waste a lot of valuable battery power. Fluorescent lamps, on the other hand, produce good lighting at high efficiency. Unfortunately, they require a dc-to-ac converter.

The low-cost circuit described here not only performs the dc-to-ac conversion, it also provides automatic shut-down when the battery reaches some predetermined voltage level, thus preventing a complete discharge. A LED indicator glows when the turn-off point is reached. Once turned off, the system draws only a few milliamperes.

Circuit Operation. When the 12-volt supply (Fig. 1) is applied to the circuit through fuse F1, switch S1, and the protective diode, D1, multivibrator IC1 starts to oscillate at a frequency determined by the setting of R2. This is approximately 10 kHz. At this time, Q1 is cut off to allow IC1 to oscillate.

As the +12 volts are applied to the R18/zener diode D2 network, 7.6 volts are applied to the emitters of Q3 and Q4. At this time, the base of Q4 is at zero voltage, thus turning this transistor fully on and developing approximately 7 volts across its collector resistor (R12). This voltage, applied via R13 to the base of series-pass transistor Q5, turns the transistor on and allows the output of IC1 to pass through R7 to driver transistor Q6. The latter, in turn, drives power transistor Q7 to its maximum output.

The collector load of Q7 is formed by the 6.3-volt winding of transformer T1. Thus, as IC1 oscillates, a high alternating voltage is developed across the 120-volt winding of T1 and applied to the two series-connected fluorescent lamps (L1 and L2), and across current-sensing resistor R17.

At lamp turnon, the voltage developed across R17 is rectified and filtered by D3 and C5 and applied across lamp-current-adjust potentiometer R16. A preselected portion of this voltage is applied to the R15/C4 network and to the base of Q4. When this voltage approximates the 7.6-volt emitter reference, Q4 starts to reduce its conductance, thus lowering the voltage developed across collector resistor R12. This action lowers the bias on series-pass transistor Q5, reducing the drive to Q5/Q7 to lower the lamp drive and reduce the voltage across R17. The circuit stabilizes lamp current preset by R16.

At initial lamp turnon, approximately 1.3 amperes will flow through Q7 until the fluorescent lamps fire. This ensures lamp start even in cold weather. Once the lamps strike, the current will range from about 0.9 ampere at 13.2 volts to about 1.1 amperes when the battery voltage drops to near 10.6 volts.

Low battery protection is provided by potentiometer R6. The selected voltage is applied via R8 to the base of Q3. In normal operation, Q3 is cut off since its base voltage is higher than the 7.6 volts applied to its emitter. If the battery voltage drops so that the base of Q3 goes below the emitter voltage, Q3 starts to conduct and its collector current flows through R10 to the base of Q2. When Q2 starts to conduct, the base drive of Q3 is further reduced until both Q2 and Q3 are latched fully on. Once latched on, the collector of Q3 will be approximately 6 volts, which are applied through R11, causing LED1—the low-voltage indicator—to glow. This voltage is also applied via R5 to the base of Q1 to bias this transistor fully on. When this occurs, pins 2 and 3 of IC1 become fully positive, thus disabling the multivibrator. At this point, battery consumption drops to about 50 mA, since Q1, Q2, and Q3 are the only active elements. Operating power should now be removed via S1.

Capacitor C4 at the base of Q4 is a high value to prevent oscillation, while C3 at the base of Q2 allows the circuit to stabilize before low voltage levels can be detected. Once the circuit is...
Since the secondary of transformer $T1$ can develop as much as 1500 volts peak-to-peak across the output, and as much as 225 volts when the lamps are lit, suitable insulation must be used at these points. Also, keep these voltages in mind when performing the adjustments on the circuit.

**Adjustments.** Before applying power, remove the connection between low-voltage-adjust potentiometer $R6$ rotor to the +12-volt end. Then set lamp-current-adjust potentiometer $R16$ so that the rotor is at the ground end. Frequency-adjust potentiometer $R2$ should be set to the $R1$ side (highest resistance).

To make a complete test, use an adjustable power supply between 10 and 14 volts, with a capacity of at least 2 amperes. Connect an ammeter (about 2 amperes) in series with the positive battery connection, and a voltmeter (20-volt range) from the cathode side of $D1$ to ground. Connect the power source.

When $S1$ is turned on, the lamps may not fire due to the low frequency of the multivibrator, and about 0.3 to 0.4 ampere will be drawn. Transformer $T1$ may also make sounds due to lamination movement, which indicates an operating circuit.

Slowly rotate frequency-adjust potentiometer $R2$ and note that the ammeter current increases and the lamps start to glow. Continue to increase the frequency very slowly until the lamps come to full brightness at a current of about 0.6 ampere. At this point, the supply current will suddenly jump to about 1.2 to 1.3 amperes. Advance the frequency for an additional 0.2 ampere, but not higher, as both output voltage and efficiency will drop.

If desired, the multivibrator can be "fine tuned" using an oscilloscope. To do this, turn the power off, set the controls as described above, remove the lamps and replace them with four 100-kΩ, 1/2-W resistors connected in series. Connect the leads across $R17$, and set the scope vertical to 5 volts/division. Turn the power on and

![Fig. 1. Schematic diagram of the Battery-Operated Fluorescent Lamp. The low-voltage cutoff point is determined by the setting of potentiometer $R6$.](image-url)
note that about 0.5 ampere flows and a 3-to-4-volt waveform appears on the scope. Slowly increase the frequency (via R2) until the scope trace peaks at about 15 volts peak-to-peak. The supply current should reach about 1 ampere at this point. Do not adjust the frequency higher than this, or the efficiency will be reduced. Turn the power off, remove the resistors, and replace the lamps.

To adjust the lamp current regulator with the lamps glowing, slowly rotate current-adjust potentiometer R16 until the current approaches 0.8 ampere and there is a decrease in light output. Then slowly adjust R16 until the current reaches 1 ampere. Lower the power supply to 10.6 volts, then re-adjust R16 for 1.1 amperes current flow. This becomes the maximum current drain at the lowest operating voltage.

Increase the supply voltage from 10.6 to 13.2 volts and note that the light output remains constant as the current decreases. With 12 volts applied, about 1 ampere will flow, and with a 13.2-volt supply, the current drops to about 0.9 ampere.

To adjust the low-voltage cutoff, reconnect R6 to the +12-volt line, and with the voltmeter still in the circuit, allow a 5-minute lamp warm-up. Reduce the power supply to 10.6 volts (or other desired low-voltage point) and slowly rotate R6 until the lamps go out and LED1 glows. Recheck this point several times. If, during operation, the lamps go out, the presence of glowing LED1 indicates that the low battery voltage has been reached, and the circuit has not been accidentally removed from the power source.

"COINSHOOTER" METAL DETECTOR

Advanced circuit reacts to coins and other precious metal objects while ignoring chunks of iron and steel

BY WILLIAM LAHR

SEARCHING FOR coins and other lost articles along beaches and in parks can be both profitable and fun. The Coinshooter, a novel and inexpensive electronic metal detector, can make such outings more productive. Employing a sophisticated, VLF induction-balance detection system that responds only to the proximity of nonferrous metallic objects, it ignores items containing iron. Moreover, the project can be adjusted to compensate for the soil's mineral content, thus minimizing false indications.

The Coinshooter can detect a dime at an air gap of four inches or a half-dollar at nine inches. It cannot detect coins buried deep in the ground, but will yield excellent results if the coins are at depths of from 1 to 3 inches. Unlike detectors that employ conventional beat-frequency oscillator circuits, the Coinshooter does not require the user to monitor the pitch of a continuous tone. Rather, it alerts the user to the proximity of nonferrous metal by generating one or more beeps. Also, it is lightweight (about 2 lb) and well balanced. Total construction cost is approximately $35, and less if salvaged parts are used.

About the Circuit. The Coinshooter appears schematically in Figure 1. Coplanar search coils are formed by placing a receiving coil (L3) over a folded-loop transmitting coil (L1 and L2) so that there is little if any coupling between them unless there is metal present in the search field. A Colpitts oscillator comprising Q1 and its associated passive components generates a 6.2-kHz signal that drives the transmitting coil. Transistors Q2 and Q3 amplify the low-level signal induced across receiving coil L3 when no metal objects are present in the search field so that a 1-volt p-p signal appears at the collector of Q3.

Capacitor C7 couples this signal to the noninverting input of voltage comparator IC1A. The input circuit of the comparator rectifies the ac signal, resulting in the generation of a slightly
negative voltage that subtracts from the positive bias voltage supplied by divider R13/R14. Potentiometers R29 and R30 determine the magnitude of the reference voltage applied to the inverting input of IC1A and hence the detector circuit's sensitivity. They are adjusted so that the voltages at the two inputs are practically equal. When the voltage at the noninverting input of the comparator becomes more positive than that at the inverting input, the output terminal (pin 1) switches to the positive supply voltage. This positive pulse toggles comparators IC1B and IC1C, which are connected in cascade and whose inverting inputs are biased to one-half the positive supply voltage. The charging of C9 via D1 and the discharging of C9 through R19 stretches the pulse. Transistor Q4 is triggered into conduction by the elongated pulse that appears at the output of IC1C, cutting off Q5.

When Q5 is cut off, Q6 amplifies the tone produced by the audio oscillator comprising IC1D and its associated passive components. The current flowing through the primary of audio-output transformer T1 and transistor Q6 increases the voltage drop across R5, and this upsets the

**PARTS LIST**

- B1,B2 — 9-V alkaline battery
- C1 — 0.033-µF, 50-V Mylar capacitor
- C2, C10 — 0.047-µF, 50-V Mylar capacitor
- C3, C9 — 1-µF, 16-V tantalum capacitor
- C4, C23 — 0.01-µF, 50-V disc ceramic capacitor
- C5 — 0.005-µF, 50-V disc ceramic capacitor
- C6, C8, C12 — 10-µF, 16-V aluminum electrolytic capacitor
- C7 — 0.1-µF, 50-V Mylar capacitor
- C11 — 0.002-µF, 50-V disc ceramic capacitor
- D1, D2 — 1N914 silicon switching diode
- IC1 — LM339 quad voltage comparator
- IC2 — LM340T-8 + 8-V regulator
- L1, L2 — Air-core inductor: 175 turns of No. 30 wire wound 9½ inches in diameter (see text)
- L3 — Air-core inductor: 550 turns of No. 38 enamelled wire on 3⅛-inch diam.
- Q1 — 2N3906 or similar npn silicon switching transistor
- Q2 through Q6 — 2N2222 or similar npn silicon switching transistor
- The following, unless otherwise specified, are 1/4-watt, 5%-tolerance, carbon-composition fixed resistors.
  - R1 — 5.6 kΩ
  - R2, R19, R26 — 22 kΩ
  - R3 — 2.2 kΩ
  - R4 — 100 Ω
  - R5 — 4.7 Ω
  - R6 — 82 Ω
  - R7 — 1 kΩ
  - R8 — 470 Ω
  - R9 — 3.3 kΩ
  - R10 — 680 Ω
  - R11 — 220 Ω
  - R12, R14, R17, R18 — 4.7 kΩ
  - R13, R15, R16, R20, R21, R23 — 10 kΩ
  - R22 — 1 MΩ
  - R24, R27 — 100 kΩ
  - R25 — 220 kΩ
  - R28 — 56 kΩ
  - R29 — 5-kΩ linear-taper potentiometer
  - R30 — 5-kΩ linear-taper potentiometer with shaft-actuated spst switch
- S1 — Spst switch (part of R30)
- SPKR — 2½-inch, 8-Ω dynamic speaker
- T1 — 1kΩ B1L miniature audio output transformer
- Misc. — Suitable enclosure, perforated or printed-circuit board, single-conductor shielded cable, hookup wire, No. 30 and No. 38 enamelled copper (magnet) wire, battery clips, battery holder, circuit-board standoffs, grommets or other suitable strain reliefs for shielded cable, PVC electrical tape or silicone cement or other suitable insulating material, 12-inch-by-12-inch sheet of ¼-inch plywood, monofilament fishing line, ⅛-inch masking tape, epoxy, hot-melt, and PVC glue, 4 feet of ½-inch O.D., schedule 125 PVC pipe, 2 feet of ¼-inch, schedule 40 PVC pipe, 90° elbow PVC pipe joint, 135° elbow PVC pipe joint, tee PVC pipe joint, PVC pipe cap, bicycle steering-bar handgrip, lead buckets, resin sealant, white paint, solder, hardware, aluminum foil etc.
bias applied to the inverting input of IC1A. As a result, the outputs of IC1A, IC1B, and IC1C go low, transistor Q4 cuts off, and transistor Q5 saturates, shunting the base drive of Q6 to ground and cutting that transistor off. This silences the loudspeaker and allows C8 to charge again to the full positive supply voltage. The higher voltage across the capacitor allows IC1A to change state again if the nonferrous metal object is still within the search field.

Iron objects or mineralized ground within the search field will produce an increase in the amplitude of the signal at the collector of Q3 and thus a less positive bias at the noninverting input of IC1A. In contrast, the presence of coins or other nonferrous metal objects within the search field will cause a smaller signal to appear at the collector of Q3 and a more positive bias at the noninverting input of the first voltage comparator. This allows the Coinshooter to locate coins and other items of interest while ignoring nails, bottle caps, and other junk pieces of iron and steel.

When a small nonferrous item quickly enters and exits the search field, the loudspeaker will generate a single beep. If the object enters and remains in the search field, a series of beeps will be produced. Its rate of repetition will vary with the settings of potentiometers R29 and R30, the size of the object, and the distance between the object and the search coil. The pitch of the beep is determined by the values of C11 and the resistances in the feedback loop, as well as by the supply voltage. Its frequency is nominally 1.3 kHz.

Power for the Coinshooter circuit is supplied by two series-connected nine-volt batteries. An IC voltage regulator provides a constant supply potential to the rest of the circuit until the battery is nearly exhausted. Quiescent current demand is approximately 10 mA, so battery replacement should be infrequent if alkaline cells are used. If desired, the Coinshooter can be powered by a single nine-volt battery and the regulator IC omitted. However, the circuit is sensitive to changes in supply voltage, and this alternative is not recommended. But, if this approach is taken, an alkaline battery must be used.

**Construction.** Procure a circular form 9/16" in diameter on which you can wind the transmitting coil. In assembling the prototype, a hamper lid was used, but a mixing bowl or cardboard cylinder would be suitable.

Wind a layer of masking tape 3/4-inch wide around the form so that the adhesive side is exposed. The tape will hold the wire and make winding the coil much easier. Wind a total of 175 turns of No. 30 enamelled copper wire around the form, keeping the wire as close to the center of the tape as possible. The last turn should exit the coil at a point on the circumference 10 inches before the starting point is reached. Fold the tape around the coil and remove it from the form. Spiral-wrap the coil tightly with masking tape. Then shape the coil assembly as shown in Fig. 2 to form the transmitting coil. (L1 is the large-diameter portion and L2 is the small-diameter section.) The coils must be shielded so spiral wrap them (starting with L1 opposite the lead wires) with 1" wide strips of aluminum foil. Cover the coils completely except for a 1/4" gap between start and finish of the foil layer. Strip a 6" piece of hookup wire and lay it on the foil so that 2" exits next to one of the lead wires. Then spiral wrap the coils tightly with masking tape, covering the foil completely.

Next, cut a disc seven inches in diameter from a sheet of 1/4-inch plywood. Lay the shaped coil assembly on the disc and trace pencil lines around the inside of L1 and both sides of L2 (see Fig. 3). Remove the coil assembly and drill a series of 1/8-inch holes spaced 1/2 inch apart along the pencil lines. Then place the shaped coil assembly back on the disc and tie it down with monofilament fishing line, looping the line through the series of holes.

Obtain a circular form 3 1/2 inches in diameter on which you can wind the receiving coil. In assembling the prototype, a glass ashtray was used, but a cardboard cylinder would also be acceptable. The form should have a slight taper to facilitate removal of the coil after it has been wound. Apply masking tape to the form as was done in winding the transmitting coil, and wind 550 turns of No. 38 enamelled copper wire, keeping the winding as close to the center of the tape as possible. When the coil has been wound, fold the tape around the windings and remove the coil from the form. Spiral-wrap the coil tightly with masking tape. Wrap the coil with foil and another layer of tape as on L1 and L2 being sure to cover the foil completely. If the two foil shields are allowed to touch when the coils are positioned, the detector will not function.

Now assemble the circuit of the Coinshooter. In the construction of the prototype, a small (5 inches by 1-
When the circuit board has been assembled and mounted in the enclosure along with the other components, place the transmitting coil assembly and the receiving coil on a desk or on the floor away from any metal. Prepare the free ends of the two shielded cables and tin their inner conductors and shields. Using clip leads, connect the color-coded cable's conductors to the transmitting coil, and the other cable's conductors to the receiving coil. Connect the coil shields to the outer cable conductors. Apply power to the circuit and connect an oscilloscope probe between Q3's collector and circuit ground.

Referring to Fig. 4, position the receiving coil near the center of the plywood disc on which the transmitting coil has been mounted. Adjust the position of the receiving coil for the minimum signal level at the collector of Q3 as indicated by the scope's beam vertical deflection. Trace a pencil line on each side of the receiving coil after the null position has been determined, and then remove the receiving coil from the disc. Drill a series of 1/16-inch holes, spaced 1/2 inch apart, along the pencil lines. Reposition the receiving coil on the disc and tie it down with monofilament fishing line, looping the line through the small holes.

Using hot-melt or epoxy glue, cement a 135° elbow PVC pipe joint in the area between L2 and L3 so that its open end points toward the gap in L1. (See Fig. 5.) Cut a 39-inch length of 1/2-inch O.D., schedule 125 PVC pipe, and drill four 1/4-inch holes in it, one above the other, approximately 2 inches in from each end. The two holes at one end of the pipe section should be 2 inches apart from each other, but the holes at the other end can be closer. Also drill two 1/8-inch holes spaced 1/2 inch above and below the two holes spaced 2 inches apart.

Slip the free ends of the shielded cables exiting the circuit-board enclosure through the 1/4-inch holes that are bracketed by the smaller holes and pass the cables through the pipe until they protrude from the far end. Run a bead of hot-melt or epoxy glue on the pipe and attach the bottom of the project enclosure to the pipe. Added mechanical support can be introduced by driving self-tapping screws through the two small holes in the bottom of the enclosure and into the matching holes that were drilled into the pipe section.

Feed the free ends of the shielded cables through the two holes at the other end of the pipe. Insert that end of the pipe into the elbow joint attached to the plywood disc so that the circuit enclosure faces away from the coil assembly. Then glue the pipe to the elbow joint using PVC cement, maintaining the orientation of the enclosure with respect to the coil assembly. (Note that PVC cement sets quickly.) Solder the conductors of the color-coded cable to the transmitting coil and the conductors of the other cable to the receiving coil. The polarities of these connections are unimportant. Connect the coil shield leads to the outer cable conductors. Insulate the solder joints using PVC electrical tape, silicone cement, or some other suitable material. Then cement the cables to the plywood disc in the area between L3 and the gap in L1 using hot-melt or epoxy glue.

Cut 6- and 9-inch lengths of 1/2-inch O.D., schedule 40 PVC pipe. Referencing to Fig. 6, assemble a handle using the lengths of pipe, a 90° elbow PVC pipe joint, a tee PVC pipe joint, a bicycle steering-bar handgrip and PVC cement. The handgrip is glued to the 9-inch section of pipe, and one of the two collinear openings of the tee should be glued to the 39-inch pipe section to which the circuit-board enclosure and the search coil assembly are attached. PVC cement is fast-setting, so work quickly and orient the handle with respect to the circuit-board enclosure as it is in Fig. 6. The remaining end of the tee will be left open until the detector is balanced.

Apply power to the circuit and reconnect the oscilloscope probe between the collector of Q3 and circuit ground. Suspend the search coil in the air away from any metal and rotate the shaft of R29 to its minimum-sensitivity setting. Monitor the scope trace and, if necessary, slightly adjust the position of L3 so that a 1-volt p-p signal appears at the collector of Q3. Pass a pair of pliers approximately three inches under the search-coil assembly while monitoring the scope trace. If the signal level decreases, shift L3 through the null point and repeat the test. The signal must in-
crease in amplitude when the pliers are brought near the search-coil assembly, or the detector will ignore coins and respond to the proximity of ferrous objects. Receiving coil L3 should be positioned as close to the null point as possible yet still provide an increase in signal amplitude when iron or steel is brought near the search-coil assembly.

Next, pass a dime about three inches under the search coil and note the slight increase in signal level as displayed on the oscilloscope. Carefully fix the positions of the coils by bonding them to the plywood disc with quick-setting epoxy cement. When the epoxy has cured, remove the scope probe and button up the circuit-board enclosure. Advance the setting of the sensitivity control until the speaker begins to beep. Then adjust the FINE TUNE control to silence the speaker. Pass a pair of pliers three inches below the search coil and note that the speaker remains silent. Then pass a dime three inches under the coil and note that the speaker starts to beep. The most sensitive area of the search coil is near its center.

The search-coil assembly can be coated with two thin applications of resin to seal it, and then it can be painted white so that it matches the PVC pipe. The coils must be bonded securely to the disc before the application of sealant and paint. To minimize the possibility of displacing the coils, use spray-on resin and paint.

If the coils have shifted position before the resin has cured, a compensating piece of iron or steel can be added to the search-coil assembly. Determine whether this has in fact happened by removing the top of the circuit-board enclosure and reconnecting the oscilloscope probe between the collector of Q3 and circuit ground. Pass a ferrous object three inches below the search coil and monitor the scope trace. If the proximity of iron or steel causes a decrease in signal level, position a small steel washer on or near receiving coil L3 to correct for the misalignment. Locate the required position by repeating the test for iron sensitivity and shifting the location of the washer until the correct response is obtained. Then fix the washer in place with epoxy cement.

**Final Assembly and Use.** Grasp the Coinshooter by its handgrip and check it for proper balance. The search-coil assembly should be parallel with and approximately 2 inches above the floor. Cut a 3-inch piece of ½-inch O.D., schedule 125 PVC pipe, and glue one end of it to a PVC pipe cap. Fill the pipe section with lead shot and tape its open end closed with PVC electrical tape. Then tape the shot-laden pipe section to the open end of the tee PVC pipe joint and recheck the balance of the project.

If it is unbalanced, untape the shot-laden pipe section, remove a little shot, tape the section closed again and reattach it to the tee PVC pipe joint. Recheck the balance of the Coinshooter. If necessary, repeat this procedure until the Coinshooter is properly balanced and feels comfortable to the hand. When the correct amount of shot has been determined, remove the pipe section from the tee PVC pipe joint, seal the shot in the pipe section with epoxy, and cement the section to the tee after the epoxy has cured. This completes assembly.

Take the finished project outdoors and hold the search coil 4 to 6 inches above the ground. Apply power to the project and adjust its controls so that the speaker emits a slow series of beeps. Lower the search coil until it is approximately 2 inches above the ground. The beeping should stop. This occurs because most soil is mineralized and affects the Coinshooter much like ferrous objects do.

The detector is now at maximum sensitivity and will detect coins at depths of from 1 to 3 inches, depending on their sizes and positions. Ferrous objects will not trigger the circuit unless they are very large or very close to the search coil or both. The Coinshooter will detect aluminum cans, caps and pull tabs, but it responds best to coins. Raise the search coil from time to time to check for the slow beeps that indicate maximum detector sensitivity. Although the circuit is very stable, the FINE TUNE control might have to be adjusted occasionally to compensate for changes in ground mineralization, temperature, and, if an unregulated power supply is used, battery voltage.

Always hold the Coinshooter so that the search-coil assembly is 1 to 2 inches above and parallel to the ground. Try to keep the search coil at a constant height above the ground. Swing the loop back and forth in front of you, making overlapping arcs. It is best to search slowly, but a coin will usually be detected even if the search coil passes over it quickly. For best results, operate the circuit as close to its switching threshold as possible.

When an object has been detected, move the search-coil assembly over it from front to back and from side to side to pinpoint its location. Keep in mind that the center of the search-coil assembly is its most sensitive point. Probe for the object with a small screwdriver or similar digging tool. If you search for coins in parks and woodlands, do so without disturbing the landscape. Always fill any holes that you make with your digging tool and place any turf that has been disturbed back in its original position.
GRAPHIC equalizers are popular audio accessories nowadays. They enable hi-fi buffs to adjust the frequency response of a stereo system to compensate for loudspeaker errors, room acoustic problems, and unsuitably balanced recordings and broadcasts. In essence, they are super tone controls that allow one to change small portions of the audio spectrum.

The 10-band graphic equalizer is the most popular type for home use. But a new design gives improved performance at low cost. It's called the Optimized Graphic Equalizer. Now, instead of equalizing one-octave bands, half-octave control is available for the ten important midrange bands. Although bass and treble suffer somewhat (there are just three controls for these), the overall design allows for better control of frequency response. Additionally, an optional real-time analyzer can be incorporated into the circuit for equalization setup.

**Design of the Equalizer.** Human hearing is relatively insensitive to frequency response errors of less than 1/8 of an octave (called the "critical bandwidth"). This is why professional equalizers have 24 to 31 bands at approximately 1/3-octave spacings. But the critical bandwidth is actually narrower in the midrange than in the bass or high treble. Also, because the vast amount of musical information occurs in the midrange, this is the most important area for high-resolution (close band spacing) equalization. Normally, equalizers designed for home use have 1-octave spacings. In order to create an economical, but very effective equalizer, the Optimized Equalizer uses 1/2-octave spacing of bands in the midrange (for five octaves), a relatively wide band in the treble range, and two in the bass.

The most important function of an equalizer is the taming of two kinds of resonances—those with gain and those with loss. But a giant "hole" in the frequency response of a system (for example, a -20-dB "suckout" in a typical second-order speaker crossover) is practically inaudible. This is because the information in a narrow notch is small and masked by nearby signals. Furthermore, it isn't feasible to equalize a narrow notch. Practically speaking, you can't set the frequency and bandwidth close enough, and the phase relationships of the notch are so poorly controlled that, even if the frequency response were right, the actual signal waveforms wouldn't sound right.

On the other hand, resonances that boost the frequency response are painfully obvious to the listener. A +3-dB resonance adds more signal to a system than a -20-dB notch removes, and since it is an error of commission rather than omission, it "pops out" at you. Also, the sound from such a reso-
nance continues in the room long after the signal to the loudspeaker has stopped. An equalizer eliminates this problem, even if it isn’t “right on” the frequency of the resonance, by reducing the energy that drives it.

Thus, it’s more important for an equalizer to cut signals than to boost them. We chose to allow only +3 dB of boost in the midrange bands, but a full 12 dB of cut. This is enough range to tame the worst resonances.

The bottom bass band of the Optimized Equalizer is just the opposite in range. It goes from −3 dB to +12 dB, with the hinge frequency of the band moving higher with more boost. This band is thus optimized to improve the bottom useful octave of home loudspeaker response, usually stretching it from 45 to 65 Hz downward.

The mid-range band is placed at about 140 Hz in the Optimized Equalizer. This covers the space between the other bands and coincides with the typical midbass hump (the one that helps speakers sell so well in the hi-fi stores). Most persons will need to reduce the gain slightly at this frequency for improved accuracy, but a full ± 8 dB is allowed because boosting this band can be fun, even if it is unrealistic.

The treble band covers the range above the last midrange band. Because of the large variations in loudspeakers and recorded material, ±10 dB is allowed on this band.

Circuit Operation. Figure 1 is a block diagram of the Optimized Equalizer. The midband frequency selection is done by the filter bank. Since the filters have gain, the signal is attenuated at the input. This prevents even the largest signals at the tape monitor terminals of your amplifier from causing clipping of the filters. By subtracting three-quarters of the signal using the filter outputs, the result is a gain of −12 dB at the filter center frequency. Next, a variable amount of the filter output is added back to the signal. When the control is set to 0 dB, the added signal cancels the subtracted signal exactly for flat frequency response.

An important point about this block diagram is that the arrangement of the input attenuator and filter bank is exactly that required for a real-time analyzer (which will be discussed next month).

The signal from the adder (which has gain to make up for the input attenuator) goes to a three-band circuit that is similar to those found in preamplifiers. The controls adjust the amount of feedback, and thus gain, in a particular frequency region.

Figure 2 is the complete schematic for the Optimized Equalizer. The power supply is a full-wave bridge rectifier (DD01-D004) with a wall-plug transformer. The use of a remote transformer obviates the need for coaxial cables (without the penalty of hum pickup). Power to IC2-IC6 is unregulated because the power-supply noise rejection of these ICs is so good that hum pickup is trivial. However, power to IC1 and IC7 is passed through an RC filter to reduce hum by 18 dB because the circuits that use these two ICs are more sensitive to supply noise.

 Resistors R202-R204 and capacitors C203 and C204 bias the ICs at 15 V. This double filter reduces the hum from the power supply to about 1 µV. The circuit could not be any quieter even with dual, fully regulated, power supplies (which would be much more expensive than the single supply used here).

 Resistors R1 and R2 form the input attenuator. Capacitor C1 reduces the attenuation at high frequencies where the filter bank
cannot clip because the filters have low gain. Reducing the attenuation here allows the reduction of the gain, and thus noise, later on. Capacitor C2 couples the attenuated signal to IC1A, a gain-of-one stage that presents a high input impedance, but can drive the low impedance of the filter bank.

Op amps IC2A through IC4B are ten parallel filters. All have a bridged-T configuration. Let's examine IC2A as an example. At low frequencies, the input signal from R22 is blocked from IC2A by the high impedance of C22. At frequencies much higher than the filter's center frequency, the low impedance of C21 bypasses the signal from R22 into the low output impedance of IC2A, preventing its amplification. At the center frequency, though, the stage has a high gain. The signal from R22 is coupled through C22 to be amplified and inverted by IC2A. The output of IC2A is coupled back through C21. Due to the phase shift of the capacitor circuits and the op amp's inversion, this feedback signal is in phase with the direct signal. Resistor R23 controls the gain and positive feedback.

The signals from R55 and the even-numbered resistors, R34 through R52, are added at the input to IC1D. The filter outputs are all inverted at their center frequencies, which forms the subtractor in the block diagram. Controls R24 through R33 adjust the amount of signal added back in IC1C, which implements the adder. The feedback around IC1C rolls off the gain at high frequencies to make up for rolling off the attenuation with C1. It thus allows better signal-to-noise ratio with flat response.

Op amp IC1B adds the last three bands to the equalizer. Consider first the bass band, controlled by R60. If it is set to full boost, then at low frequencies the input signal is applied to IC1B through relatively low-valued resistor R59, for little attenuation. Feedback comes from R62, R61, and R60; very large values imply little feedback and thus a large gain. If R60 is set to the other end, there is more attenuation and more feedback, for a net attenuation. At high frequencies, the bass control is bypassed by C26 and C27 and the midbass control is coupled in through C28. Above the midbass frequencies, C29 and C30 bypass the midbass control, and C31 couples the high-frequency control to IC1B.

The output of IC1B is coupled through C32 to eliminate the 15-V dc bias from the output. Resistor R72 increases the output impedance to about 600 ohms and prevents possible oscillation of IC1B due to highly capacitive connecting cables.

Construction. The Optimized Equalizer, except for the power supply input connectors and options, is built on two pc boards. The foil patterns for these boards are shown in Fig.3, and the parts placement diagrams are given in Fig. 4. By placing all the controls on one board (the vertical board) and most of the remainder of the unit on the horizontal board, front panel space requirements are minimized. This makes for an efficient, compact assembly. The boards are connected
Parts List

IC1 through IC7—RC4136 quad op amp
The following are 1/4-W, 5% carbon-film resistors unless otherwise noted:
R1, R101, R202 through R204—100 kilohms
R2, R102—8.2 kilohms
R3, R5, R103, R105—82 kilohms
R4, R104—2.7 kilohms
R6, R106—3.9 kilohms
R7, R107—120 kilohms
R8, R108—5.1 kilohms
R9, R109—160 kilohms
R10, R110—7.5 kilohms
R11, R111—240 kilohms
R12, R112—11 kilohms
R13, R113—330 kilohms
R14, R114—15 kilohms
R15, R115—470 kilohms
R16, R116—20 kilohms
R17, R117—620 kilohms
R18, R118—30 kilohms
R19, R119—910 kilohms
R20, R120—43 kilohms
R21, R121—1.3 megohms
R22, R122—56 kilohms
R23, R123—1.6 megohms
R54, R154—16.2 kilohms, 1% metal film
R55, R155—1.62 kilohms, 1% metal film
R56, R156—24.9 kilohms, 1% metal film
R57, R157—36 kilohms
R58, R158—3 kilohms
R64, R71, R164, R171—5.6 kilohms
R72, R172—560 ohms

Horizontal Board
C1, C101—390-pF, 5% capacitor
C2, C102, C123, C124, C132, C203, C204—10-µF, 25-V aluminum electrolytic
C3 through C22, C103 through C122—0.0022-µF, 5% polyester film capacitor
C25, C125—0.001-µF, 5% polyester film capacitor
C26, C126—0.22-µF, 10% polyester film capacitor
C31, C131—0.01-µF, 10% polyester film capacitor
C206, C207—0.1-µF, +80/-20% ceramic disc capacitor

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Vertical Board

- C23—10-µF, 25-V aluminum electrolytic capacitor
- C26, C27, C126, C127—0.1-µF, 5% polyester film capacitor
- C29, C30, C129, C130—0.022-µF, 5% polyester film capacitor
- R24 through R33, R63, R66, R124 through R133, R163, R166, R169—50-kilohm slide potentiometer
- R34 through R53, R134 through R153—33 kilohms
- R59, R62, R65, R67, R159, R162, R165, R167—5.6 kilohms
- R60, R160—22 kilohms
- R61, R161—9.1 kilohms
- R68, R70, R168, R170—1.5 kilohms
- S1, S2—Dpdt nonshorting switch

Power Supply

- C201, C202—1000-µF, 35-V aluminum electrolytic capacitor
- C205—0.1-µF, ±80/-20% ceramic disc capacitor
- D201 through D204—IN4002 (or equivalent)
- R201—10-ohm, 1/4-W, 5% resistor
- J1 through J4, J101 through J104—Phono jack
- T201—24-V, 170-mA wall-plug transformer (Dormeyer PS14201 or equivalent)
- Misc.—No. 20 AWG bus wire (6'), ribbon cable (14 conductor, 7½"), angle bracket (#6-32 threaded, one side, 8), #6 x ¾" sheet metal screw (11), #6-32 x 1/4" machine screw (6), chassiss, 16-pin DIP socket, 14-pin DIP socket.

Note: The following are available from Symmetric Sound Systems, 556 Lynn Rose Ct., Santa Rosa, CA 95404 (707-546-3895): complete Optimized Equalizer kit (EQ-4) with unfinished walnut end panels at $100; complete Optimized Analyzer kit (AN-1) at $60. Also available separately: horizontal and vertical pc boards for Equalizer (EQ-4PC) at $17; Analyser and interconnect pc boards (AN-1PC) at $13; slide potentiometers #EQ-4SP, $0.95 each. Quad op-amp IC #4136, $1.75 each. Set of IC’s for the analyzer #AN-1IC, $6.00. Wall plug transformer #EQ-4PT, $7.50. Minimum order $10.00. All prices include shipping on prepaid orders in the U.S. Canadians add $4.00 shipping and handling. California residents add sales tax.
Fig. 3. Foil patterns for the Equalizer pc boards together with #20-AWG bus wire between adjacent pads. The bus wire is stiff enough to make a rigid assembly of the boards, with easy access to both sides of boards for testing and experimenting.

Components should be soldered to the horizontal board first, in order of resistors, capacitors, jumpers, and ICs. Be careful to observe the index marking on the ICs and the polarity of the electrolytic capacitors. Next solder components to the vertical board—slide potentiometers first, then resistors, capacitors, and switches (observe the polarity on C123).

To connect the boards, push #20-AWG bus wire or solid uninsulated wire through the pads in the long line on the vertical board from the back side, and solder to the pads. Taper the length of these pieces of wire from 3/4" on one end to 3" on the other end. Starting on the long end, and with the copper-clad sides of both boards facing each other, push the leads through the matching pads on the horizontal board, working your way to the short end. Bend the horizontal board, and thus all the wires, until it is perpendicular to the vertical board and flush against it. Solder all the wires.

Wire the switches, jacks, and boards together according to the schematic (wires A through E, M, and V through Z). Wire the power supply on a terminal strip, and connect it to the horizontal board (wires J through L). A foil pattern for an interconnect board is given in Fig. 5. One 16- and one 14-pin DIP socket are wired to this board. The sockets are used to connect to the real-time analyzer, which will be covered in Part 2.

Because of the compactness of the pc-board assembly, many mechanical configurations are possible. In the prototype, the vertical pc board was attached to two pieces of walnut. The rear of an inverted "U" chassis was also attached to the walnut. The chassis provides marking for all the controls, switches, and jacks. Grounding the chassis to circuit ground shields the circuit from radio-frequency interference and electrostatic pick-up of 60 Hz and its harmonics.
Installation. Most component high-fidelity systems can accommodate signal processors, such as the Optimized Equalizer, through the tape-monitor loop. Connect the “tape out” or “tape record” output of your amplifier to the equalizer’s input. Then connect the equalizer’s output to the “tape in,” “tape monitor,” or “tape play” jacks of your amplifier. Switch the amplifier’s tape monitor switch to “on” to enable the equalizer. The tape monitor function is replaced on the equalizer. Connect your tape deck to the equalizer as it had been connected to the amplifier.

Some amplifiers have separate tape source switches to enable you to play one source while recording another. In this case, you will have to use your tape source switch as your selector. Switch the selector switch to tape, so that the signal always passes through the equalizer.

Equalizer Adjustment. There are a number of different techniques available to adjust your equalizer; these vary in convenience, cost, and accuracy. Audiophiles with very good familiarity with live music can adjust the bands by ear to match their idea of the way the music should sound. A different technique is to use a test record, perhaps with the aid of a sound-level meter, to adjust the bands for flat response.

An easy way to adjust an equalizer is with a real-time analyzer. Although this can be a costly audio accessory, it’s not in this case. The equalizer was designed to inherently contain much of the circuitry of the analyzer. In Part 2, we will describe the design, construction, and use of the analyzer.

With the high performance and build-it-yourself economies of the Optimized Equalizer/Analyzer, you can anticipate an impressive improvement in the sound of your system.
Part 2—An integral analyzer for accurately setting up the audio equalizer in Part 1

In the first part of this article, we presented a new kind of equalizer circuit that offers high performance at an economical cost. In this second part, we will describe a Flatness Analyzer, an accessory you use to rapidly and accurately adjust the equalizer. The details follow.

**Circuit Operation.** Figure 6A is a block diagram of the equalizer/ analyzer combination (part of which is identical to Fig. 1). The analyzer plugs directly into the equalizer. Figure 6B is a block diagram of the equalization test procedure.

Here's how the Flatness Analyzer tests one channel (the right) of the Optimized Equalizer. Pink noise is applied to the right-channel input of the equalizer. The equalized output of the right channel is then fed through an amplifier and speakers into the room. From here, the microphone picks it up.

The signal is then amplified by the microphone preamp and applied to the left-channel input of the equalizer, as well as two filters in the analyzer. The outputs of these 12 filters drive simple biased-diode detectors and a bank of 12 meters to show the deviations from flatness. If the system response is flat, all meters will have equal deflections. The output of the left channel is grounded to prevent the amplified microphone signal from passing back out through the left speaker and perturbing the measurements or causing oscillations.

To test the left channel, the interconnecting plug is reversed and offset in its socket, and the above procedure is repeated with left and right channels reversed.

**Figure 7** is the schematic of the analyzer. Integrated circuits IC2 and IC3 constitute a digital white-noise generator. The circuits in IC3A and IC3B form a square-wave oscillator with an output frequency of about 100 kHz. This clocks 18-stage shift register IC2, which keeps shifting the output of IC3D, the exclusive-OR function of the 14th and 17th stages of the shift register. These taps (14 and 17) are chosen so that the register outputs random ones and zeros; it only repeats after going through all but one of the 2^17 possible states. This is called a pseudo-random sequence generator (since it repeats, it isn't truly random). Its output spectrum is very white if you pass the digital output through a low-pass filter. Integrated circuit IC3C and its associated components ensure that IC2 cannot get locked up in the all-zeros state.

Components R29 through R32 and C20 through C23 are a pinking filter. The gain vs. frequency of this network falls off at 3 dB per octave on the average, about half as fast as a single RC filter. The noise is amplified by IC4B and rolled off at high frequencies to compensate for the increased gain of the testing channel at high frequencies (due to the reduction in input attenuation as explained previously).

The output is ac coupled with C25, and its level is controlled with R32. The level could be controlled with the stereo's master volume control, but having a control on the analyzer is a real convenience. The signal from the level control now passes to the channel under test.

The stereo speakers convert the noise to sound, which comes back for analysis through the microphone, MIC1. A small electret is used here, which has typical accuracy of ±1 dB with help from the preamp, IC1B. This stage provides a gain of 27, and C33 and R44 tame an upper-midrange peak that is common to most inexpensive electret microphones.

The microphone signal is further amplified in IC1A and passed through R48 and C32 to the testing channel's filters. Resistor R48 is provided as protection in case the input to the equalizer is not disconnected.

Besides the ten filters in the equalizer, IC1C and IC1D filter the frequencies around 40 to 100 Hz and 140 Hz to help adjust the bottom bands of the equalizer.

The filtered signals from the equalizer are ac-coupled by C1 through C10 (to remove the dc components) and detected by D3 through D12. To minimize the errors due to the on voltage of these diodes, a small current is passed through D15 and buffered by IC4A to offset the positive side of the meters by approximately the diode on voltage. As a result, the meters respond to the average value of the noise level, which is a much more accurate parameter than the peak response frequently used in such an analyzer.

The outputs of IC1C and IC1D are passed through RC filters R18, R19, R24, and R25 and C12 and...
C16 to reduce the fluctuations of the bottom band meters and to reduce the gain, in order to make up for the effect of the attenuator at the input of the testing channel on the ten other bands.

Resistor R17 and diode D16 provide a +9-V supply for the microphone and white-noise generator, and also supply bias for ICl.

Switch S7 allows the response of the analyzer to be observed without the speaker-microphone link, to see how flat it is. This calibration permits adjustments to be made that will provide compensation for component tolerance errors, especially in the meter sensitivities (±1 dB) and pinking-filter components.

**Construction.** Figure 8 is the foil pattern for the analyzer pc board, and Fig. 9 is the foil pattern for the interconnection pc board. A component-placement diagram for the analyzer is given in Fig. 10.

Solder all components to the board, except the slide potentiometers. Don't forget the two jumpers. Carefully orient the ICs, diodes, and electrolytic capacitors according to pin number or polarity. Integrated circuits IC2 and IC3 are CMOS, and thus static-sensitive; so don't remove them from their conductive packaging until you are ready to install them. Then discharge yourself, your soldering iron, and the pc traces to ground.

Connect the microphone element, MIC1, to the shielded pair cord and solder the cord to the appropriate pc board holes—red wire for positive, white for signal, and shield for ground. Connect a stiff piece of wire over the shield and solder to the two holes right behind it to act as a strain relief.

The connection to the equalizer is through a DIP plug. Cut a standard DIP-plug to DIP-plug 16-wire cable in half and solder the unterminated wires to the appropriate pads of the DIP pattern on your board (the wires will alternate sides). Or just install a whole DIP-plug right in the pattern. Pass the wires across R35's position, and then mount R35.
...EQUALIZER

PARTS LIST
C1 through C10,C12,C13,C16,C17,C24, C30, C32—10-µF, 25-V aluminum electrolytic
C11,C28—0.1-µF 50-V ceramic disc
C29—10-µF, 25-volt electrolytic
C14—0.0047-µF, 5% polyester capacitor
C15,C18,C19,C25—0.1-µF, 5% polyester capacitor
C21
C20
C15,C18,C19,C25—0.1-µF, 5% polyester capacitor
C22,C26,C34—0.0022-µF, 5% polyester capacitor
C23—0.001-µF, 5% polyester capacitor
C27—24-pF, 5% capacitor
C31—not used
C33—39-pF ceramic disc capacitor
D1 through D15—1N4148 diode
D16—9.1-V zener (1N5239 or 1N960)
C1—RC4136 quad op amp
C2—CD4006 18-stage shift register
C3—CD4070 quad ex-OR gate
C4—LM358 dual op amp
M1,M12—200-µA 1-kilohm edgewise meter
M11—Electret microphone element
P1—16-pin DIP plug
The following are 1/4-W, 5% carbon-film resistors unless otherwise noted:
R1 through R10,R40—470 kilohms
R11,R39,R46,R49—1.5 megohms
R12 through R16—Not used
R17,R20,R26,R28,R48—2.2 kilohms
R18,R19,R50—8.2 kilohms
R21—300 kilohms
R22,R34,R43—3.9 kilohms
R23—39 kilohms
R24,R25—11 kilohms
R26—62 kilohms
R29—270 kilohms
R30,R37—150 kilohms
R31,R41—47 kilohms
R32,R33—15 kilohms
R34—50-kilohm potentiometer
R42—100 kilohms

Fig. 7. Schematic of the circuit in the analyzer.
...EQUALIZER

over them as a strain relief. Also mount the other slide potentiometer in its proper location.

In the prototype, the bases of the edgewise meters were glued to the pc board and wired with short jumpers. It is a good idea to use stick-on rubber feet to prevent shorting to the chassis of the equalizer or scratching it during use.

Since the analyzer is a sophisticated accessory and not for display, to save effort and expense, you need not put it in a fancy chassis.

Adjustment and Use. Using the Optimized Equalizer and the Analyzer combination is easy because all the information you need is right in front of you at all times.

With the power off, connect the equalizer outputs to your stereo. Do not connect the equalizer inputs to anything. Connect the analyzer to the equalizer and turn the slide pots to OFF. Set the TEST switch to EQ and the EQUALIZER switch to IN. Set all the equalizer controls to 0 dB. Place the measuring microphone at your favorite listening location. Apply power to the equalizer/analyzer and your stereo.

Adjust the mike gain upwards until there is significant deflection of some of the meters. This point shows how large the room noise is. Back down on the gain until there is no more than 10% deflection on any meter. Now slowly advance your noise-level control and stereo-volume control until you are getting an average of over 70% of full deflection on your meters. Depending on the ambient levels in your room, this is likely to be relatively loud.

Adjust the bands of the channel

Fig. 8. Foil pattern for the analyzer pc board.

Fig. 9. Foil pattern for connector board to equalizer.

WHAT'S WRONG WITH THE FLATNESS ANALYZER?

According to traditional thinking, there is quite a bit wrong with the analyzer. First, its output devices are meters. Unlike bargraph LEDs, meters cannot be easily read from far away. They are also slow and cannot show the dynamics of music well, due to mechanical inertia. But we are not building a music analyzer; we are building a flatness analyzer. It is designed to be placed next to the equalizer so that the controls can be adjusted while watching the meters. Only the microphone needs to be usable over a distance, and it comes with a long cord.

The slowness of the meters is in fact desirable because it evens out the fluctuations in the noise levels. Actually the meters act as filters without extra components to do that filtering (except in the lowest bands, where the fluctuations are slow enough that additional filtering is desirable). However, the most important reason for using meters is that they give better resolution and “feel” for that signal level.

Their fluctuations can be averaged visually much faster and more accurately than LEDs, especially in designs with 2.5 dB/step LED resolution.

Next, the Flatness Analyzer will not analyze music. Since the signal levels in the testing channel must be adjusted to drive the meters appropriately, this channel cannot be used to process music. This precludes the fascinating light-shows of some analyzers, but it is necessary for the economy of using the equalizer’s filters. We’re out for performance here, not a show.

Finally, the Flatness Analyzer does not have a top-end meter to help adjust the equalizer’s 10-kHz control. One is easily added, but it is not worthwhile for a number of reasons. First, a microphone that has even marginally predictable response in the top octave will cost more than the entire equalizer/analyzer combination; using it would produce the worst kind of diminishing return on your investment. Secondly, recorded music in the top octave is notoriously variable in relative level due to varying microphone techniques and engineer’s tastes. Finally, all speakers, microphones, musical instruments and ears are extremely directional at high frequencies. Unlike the situation at lower frequencies where most of the signal you equalize has been reflected from room boundaries; at high frequencies, you would be equalizing the direct signal from the loudspeakers. The desired ratio of this signal level to the reverberantly measured levels at other frequencies is not well controlled.

Thus, no one equalizes for a flat high end. Rather, they try to accomplish some smooth roll-off. The author strongly recommends setting this band by ear and re-setting it (and perhaps the top two or three narrow bands slightly) according to the particular piece of music being played. ☃
...EQUALIZER

under test by reducing the level of the band corresponding to the meter with the highest deflection. After you have adjusted a few bands this way, continue by moving the bands either up or down to come as close as possible to uniform deflection of all bands. Adjust the noise level as necessary to keep the average deflection at about 70%.

The noise source, being pseudo-random, audibly repeats every 1.5 seconds, and the meters will show this periodicity. When fine tuning, visually average the motion during this interval. When the result is close to flat, switch the TEST switch to CAL, adjust the MIKE GAIN for 70% average deflection, and observe the errors of the test system. Then switch back to EQ and fine-tune the equalizer to match the CAL response, which will be slightly different than truly flat. Then turn everything off, switch the connection from the analyzer to the equalizer, and repeat for the other channel. Then remove the analyzer and connect the equalizer normally.

Hints on Equalizing. Over the long term, the sound from your system will be exceptionally smooth and accurate. But be wary of short-term reactions. After listening so long to the errors that your system and room make, your mind gets accustomed to these distortions of reality and expects them. Thus, any change toward either more or less realistic sound is initially perceived as unnatural. Also, the equalization technique given will reduce the overall level somewhat. Unless you compensate by increasing the volume control setting, you are likely to initially consider the sound to be poorer when equalized.

But give yourself about 15 minutes with your de-resonated stereo and then switch to unequalized. You will notice a hollow, boxy sound that you missed before because you were so used to it. Now simply switch back to equalized sound and you will find some really fine listening.

The concept of having the analyzer use some of the circuits in the equalizer is an interesting one and makes for economy in achieving both analysis and equalization. In addition, the recognition that a limited amount of boost and much more “cut,” are required for room/speaker equalization is something we have not seen discussed before. It differs sharply from conventional practice, which provides symmetrical (more or less) boost.

The measured characteristics of the various filters in the analyzer and equalizer confirm the statements made in the article. It is interesting to note that using only the extreme controls (40 Hz and 10 kHz) one can simulate quite well the effect of a conventional tone control system. The distortion of the equalizer was negligible and well within the stated limits. The noise which was below our measurement limit appeared to meet the claimed performance comfortably.

Following the instructions, we used the system to equalize a stereo music system. It would be helpful if the meters could be marked to match the corresponding slider controls; we had to use some “cut and try” methods in doing the equalization, but the end result seemed to be reasonable. According to a spectrum analysis of the “pink noise” from the system, it is not quiet pink. However, since one uses the meters to read the noise spectrum as well as the equalized acoustic spectrum, this error is of no importance. —Julian Hirsch

TESTING THE EQUALIZER/ANALYZER

Boost and attenuation effects of the ten filter points.

The figure shows the frequency response of the equalizer. The gain at each frequency is indicated by the level of the corresponding line. The meters on the analyzer are used to adjust the equalizer for a flat response. The equalizer was adjusted to match the response of the analyzer with the equalizer in place. The resulting response is shown in the graph.

Fig. 10. Component layout on analyzer pc board.

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We'll give you tomorrow.
HERE IS AN easy-to-build battery-operated 3½-digit thermometer, which we call “Lidith” for Liquid-crystal Digital Thermometer. It can accurately measure temperatures from -13°F to +185°F. Basic accuracy is better than ±1° over this range and averages better than ±0.5° from 0°F to 100°F. Each degree is divided into 10 equal parts, giving Lidith a 0.1°F resolution. Readout is on a ½” liquid-crystal display.

With some simple circuit modifications, Lidith can perform other functions, such as reading the temperature in °C and displaying both indoor and outdoor temperatures.

**Circuit Operation.** Shown in Fig. 1 is the schematic diagram of Lidith. (See Box for details on sensors.) Resistor R11 is the series voltage dropper for the 6.8-volt zener diode in the temperature transducer (IC2). The R12/C6 network provides additional stability if the transducer is used as a remote sensor. Resistors R9 and R10 form a precision voltage divider to insure that the proper proportion of the transducer’s output voltage goes to the digital panel meter (DPM) circuitry.

Several points should be noted about the IC2 circuit. At room temperature (77°F), the transducer’s output from pins 1 and 2 to pin 3 is nominally 2.98 volts and increases by 10 mV for every 1°C or 1.8°F increase in temperature. This potential is measured with respect to +9 volts, not ground. This means that at 77°F, pins 1 and 2 are at -2.98 volts, with respect to +9 volts.

The heart of the DPM is the Intersil ICL7106 single-chip 3½-digit MOS A/D (analog-to-digital) converter that drives the LCD. The 7106 uses dual-slope conversion, in which nonlinearities tend to cancel out. Therefore, the circuit does not require extremely accurate or stable (and expensive) components. Also, as long as it remains unchanged for a single conversion cycle, the clock frequency does not have to be precise or extremely stable. The only real requirement is a stable current reference.

In addition to ease of use and relatively low cost, the 7106 has several other features that make it ideal for use in Lidith. Since the thermometer employs CMOS circuitry, it consumes little current (about 0.8 mA). It has true auto-zeroing, will directly drive LCD displays, and has a guaranteed ±1-count accuracy over its entire ±2000-count range.

The RC network for the 7106’s inter
Fig. 1. Most of the components are supplied with the meter evaluation kit as shown within dashed lines. Temperature sensor and other components are connected to kit as shown here.

### PARTS LIST

<table>
<thead>
<tr>
<th>Component</th>
<th>Value/Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>9-volt battery</td>
</tr>
<tr>
<td>C1</td>
<td>0.1-μF capacitor*</td>
</tr>
<tr>
<td>C2</td>
<td>0.07-μF capacitor*</td>
</tr>
<tr>
<td>C3</td>
<td>0.22-μF capacitor*</td>
</tr>
<tr>
<td>C4</td>
<td>100-pF capacitor*</td>
</tr>
<tr>
<td>C5</td>
<td>0.01-μF capacitor*</td>
</tr>
<tr>
<td>C6</td>
<td>0.1-μF capacitor</td>
</tr>
<tr>
<td>C7</td>
<td>0.1-μF capacitor</td>
</tr>
<tr>
<td>C8</td>
<td>1-μF capacitor*</td>
</tr>
<tr>
<td>C9</td>
<td>10,000-ohm resistor</td>
</tr>
<tr>
<td>R1</td>
<td>100,000-ohm resistor</td>
</tr>
<tr>
<td>R2</td>
<td>0.1-μF trimmer potentiometer*</td>
</tr>
<tr>
<td>R3</td>
<td>10,000-ohm resistor</td>
</tr>
<tr>
<td>R4</td>
<td>47-ohm resistor</td>
</tr>
<tr>
<td>R5</td>
<td>1-μF capacitor*</td>
</tr>
<tr>
<td>R6</td>
<td>12,000-ohm resistor</td>
</tr>
<tr>
<td>R7</td>
<td>5000-ohm multi-turn trimmer potentiometer</td>
</tr>
<tr>
<td>R8</td>
<td>47K resistor</td>
</tr>
<tr>
<td>R9</td>
<td>4.7K resistor</td>
</tr>
<tr>
<td>R10</td>
<td>100-ohm resistor</td>
</tr>
<tr>
<td>(C_3)</td>
<td>100-μF capacitor</td>
</tr>
<tr>
<td>(C_5)</td>
<td>0.1-μF capacitor</td>
</tr>
<tr>
<td>(C_6)</td>
<td>0.1-μF capacitor</td>
</tr>
</tbody>
</table>

Note: The following are available from Magiland, 4380 S. Gordon, Fremont, MI 49412: Kit containing one LM3911H-46, R9, and R10 for $9.95 plus $4.50 for shipping & handling (total $14.45); or kit containing two LM3911H-46s, R9, and R10 for $19.80 plus $9.00 for shipping & handling (total $28.80).

---

A stable 2.8-volt reference potential between pin 1 (V+) and pin 32 (COMMON) is provided by the 7106. Resistors R1 and R4 form an adjustable voltage-divider network that applies a suitable proportion of this reference voltage to pin 36 (REF HI) and pin 35 (REF LO). Adjustment of R4 is made for a potential of 0.110 volt (110 mV) between REF HI and REF LO. In Lidith, R4 is basically a scale-adjust trimmer potentiometer.

Another adjustable voltage-divider network that uses the 7106's 2.8-volt reference is made up of R6, R7, and R8. Notice that temperature-adjust trimmer Ri's wiper is connected through filter resistor R5 to pin 31 (IN HI) of the 7106.

Once the thermometer is calibrated, with R7 at a fixed position, IN HI is at a fixed voltage. For the DPM to display 00.0, its IN LO (connected to the transducer's voltage-divider network) must be exactly equal to its IN HI point. Thus, after calibration, the voltage at R7's wiper must be identical to that coming from the transducer's R9/R10 divider network (and connected to IN LO) when the transducer's temperature is at 0°. We can conclude, then, that R7 can be viewed as a 0° trimmer pot. However, since 0° F is not easy to achieve, R7 will actually be set for a display of 32.1 when the transducer is immersed in ice water.

As the transducer's temperature rises, its output at pins 1 and 2 becomes more negative, with respect to +9 volts. This more-negative potential is felt at the 7106's IN LO input. When IN LO becomes more negative, with respect to IN HI (which is set at a constant voltage after calibration), the 7106 senses this as a positive voltage at its input, since IN HI is now more positive, or less negative,
than IN LO. Therefore, the DPM displays a positive number.

When the transducer’s temperature goes below 0°, IN LO is less negative than IN HI and the DPM indicates a negative temperature.

The 7106 directly powers all segments of the LCD. Pin 21 goes to the display’s backplane, while the frontplane segments connect to pins 2 through 25, excluding pin 21, which connects to the decimal point between the units and tenths decades in the display. Between the decimal point and pin 21 is a CMOS inverter that provides the proper ac voltage with an insignificant dc offset. It may seem wasteful to use an entire 4001 for this trivial task when a single MOS transistor would do the same job, but a 4001 is less expensive and more readily available.

**Construction.** Unless you can obtain a suitable 3½-digit LCD at reasonable cost, we strongly recommend Intersil’s ICL7106EV/KIT Single Chip Panel Meter Evaluation Kit. It is available from Jameco (see Parts List) and other Intersil distributors. If you are set on building your thermometer from scratch instead, follow Fig. 1 and the pin configuration guide for the LCD you buy.

Except for the remote sensing transducer, all thermometer components mount on the Evaluation Kit’s circuit board. Build the Kit following the instructions supplied with it. Then, referring to Fig. 2, replace R1 supplied with the Kit with a 22,000-ohm 5% (or better) tolerance carbon or metal-film resistor. (If you can adjust R4 for 0.115 volt or more between TP2 and TP3, R1 need not be changed.) Eliminate the battery holder, specified jumper, and banana jacks. Drill holes for and mount the extra circuitry as shown. Refer back to Fig. 1 and interconnect all on-board components.

A 1” to 2” (25.4- to 50.8-mm) length of 3/16” to 1/4” (4.8- to 6.4-mm) inner-diameter thin-walled brass or copper tubing should be used as a heat sink for the transducer if you plan to measure air temperatures. If you plan to use Lidith primarily for taking body and liquid temperatures, you can omit the tubing. Use a length of flexible three-conductor cable to interconnect transducer and circuit assembly. The cable can be up to 50’ (15.2 m) long with no problems.

Referring to Fig. 3, slip the metal tubing onto the cable as shown. Then remove about 1” of the cable’s outer jacket and prepare the ends of the conductors. Slip a length of plastic tubing over each...
coats conductors conductor. Using a heat sink between transducer and tie points, solder the conductors of the cable to the leads on the transducer. Then spray several coats of plastic insulation (such as GC's Koloid K-29 or Clear Acrylic Plastic) over the connections and exposed wires. Alternatively, dip the entire transducer assembly in GC Liquid Tape. When the coating dries, push the plastic tubing down until it contacts the transducer's body and covers all bare wires.

Clean the transducer and metal tubing with fine steel wool or sandpaper. Referring to Fig. 4, solder the transducer to the tube, taking care to be sparing with the heat.

Finally, use epoxy putty to make a waterproof probe out of the transducer assembly. Prepare the putty according directions and then wet your hands and form a rough cylinder around the transducer assembly. Do not be concerned if your work appears messy. Just make sure the transducer and connections are completely sealed. With damp hands, roll the rough cylinder between your hands until it is smooth and nearly perfectly cylindrical and has a blunt cone-shaped tip.

Mount the thermometer circuit inside a housing large enough to accommodate it and its battery.

Calibration. If possible, the following reference-voltage adjustment should be performed with the aid of a digital multimeter. However, a good-quality analog voltmeter can be used if its input impedance is 1 megohm or greater. If you have a laboratory thermometer, you can do away with the need for a meter altogether, but calibration will take considerably more time. (More about this later.)

Turn on the power and let the thermometer warm up for at least 2 minutes. Then, with the meter set to its lowest range, connect the negative prod to TP3 (actually a jumper) and positive prod to TP2. Referring to Fig. 2, carefully adjust R4 for a reading of 0.110 volt.

To calibrate the thermometer, you will need a plastic bucket filled about three-quarters full with compact clean snow, ice chips, or ice cubes. Pour in enough cold water to nearly fill the bucket. Place the transducer probe in the center of the ice/water mixture and wait a few minutes until the LCD stabilizes at some number.

Vigorously stir the ice mixture and adjust R7 for a display of 32.1. This display figure is more desirable than the usual 32.0 because you will most likely be performing calibration in a warm room where ice in water will be melting. In any event, what you are really measuring is the temperature of the water, which will not be exactly 32°F. If Liddith is calibrated exactly as described above, there are only two possible sources of error left—the transducer's slope and linearity errors. Fortunately, the transducer specified is almost perfectly linear. According to the conversion specifications, the linearity of the LM3911 is typically less than ±0.05%. The only possible significant error left, then, is a slight slope error. With a laboratory thermometer and some patience, even this error can be removed.
necessary, for bucket R4 until Lidith’s display indicates exactly thermometer its DMM and (OUTDOOR) midpoint.) L1.13911 ï R7 exactly IC2* is exactly as described above. (If a DMM is not available, initially set R4 to its midpoint.) Place the probe and lab thermometer in warm (about 120° F) water and, while stirring the water, adjust R4 until Lidith’s display indicates exactly the same temperature as the lab thermometer. Then place the probe in a bucket of ice/water and adjust R7, if necessary, for a reading of 32.1. Return the probe to the warm water and, if necessary, readjust R4. Repeat the immersion-and-adjustment procedure until it is no longer necessary to trim the settings of the potentiometers.

**Using the Thermometer.** In addition to the obvious use of measuring room and ambient temperature, Lidith is ideal for measuring temperatures in pools, for isolating excessively warm electronic components in an operating circuit, as a remote-indicating freezer or refrigerator thermometer, and as a medical thermometer. (If you calibrate accurately for 98.6° F against a good-quality oral mercury thermometer, the accuracy of Lidith can approach ±0.1° F over a 92° to 110° F range.) The Celsius version can also be used by auto hobbyists as a water-temperature monitor.

To accurately measure outside-air temperatures, you need both an accurate thermometer like Lidith and a suitable thermometer shelter. (For details on measuring outside-air temperature, see pages 23 and 25 of Unique Electronic Weather Projects published by Howard W. Sams & Co., or refer to some other suitable book on weather instruments.)

If you turn on Lidith only when you wish to know the temperature and leave the power off at all other times, a standard 9-volt battery should last more than a year. For a continuous display, omit S1 and use six alkaline D cells in series instead of the 9-volt battery. In continuous use, the D cells should last about a year or more.

The thermometer can be used to measure temperatures in two different locations, such as indoors and outdoors, using the circuit shown in Fig. 5. Bear in mind, however, that if you select two LM3911H-46 transducers at random, one of the temperatures measured will typically be off by 5° to 10° due to the offset error of the devices. However, if you use a pair of custom-matched transducers (see Parts List), your maximum error will be ±2° F.

With a few changes in component values, you can make Lidith measure temperatures in Celsius over a range of from −25° to +85°C.

The following changes are required for the Celsius version. First, change C2 to a 1-µF Mylar capacitor, R2 to a 220,000-ohm, 5%-tolerance carbon-film resistor, and R4 and R7 to 10,000-ohm, 15-turn trimmer potentiometers. Then adjust R4 so that the potential between TP2 and TP3 is 0.500 volt. Also, change R6 to 20,000 ohms, R8 to 22,000 ohms, and R10 to a 10,000-ohm, 1%-tolerance precision resistor. Calibrate by adjusting R7 for a reading of 00.1 on the LCD when the probe is immersed in an ice/water mixture, as before.

**Summing Up.** Lidith is a truly state-of-the-art precision digital thermometer. With a few minor changes, it can be “tailored” to your needs. And, in ordinary use, it is highly energy-efficient, thanks to the use of low-power MOS circuitry and liquid-crystal display.
POOR DRIVING habits can reduce fuel economy by up to 50% regardless of how well-tuned and maintained the vehicle. In the era of high-cost energy and shortages, you want to get as much as possible from every drop of fuel your car burns. One good way to do this is by using a device such as the Econometer described here. It constantly and accurately monitors the relative fuel consumption of your car so that you can adjust your driving technique accordingly.

The Econometer is an electronic device that keeps tabs on intake-manifold vacuum. It has a display consisting of a row of eight LEDs. At idle, four or five LEDs normally glow. With your vehicle in motion, more or fewer LEDs glow, the maximum number (high vacuum) corresponding to high engine rpm and a small throttle opening and the minimum indicating low rpm and open throttle. High vacuum conditions give maximum fuel economy.

You will not be able to maintain high vacuum under all driving conditions. Naturally, accelerating from a standing start, driving up a steep grade, or hauling a heavy load all take more fuel than cruising on a level surface with a light load. But by observing the Econometer, you will be able to avoid using more throttle than necessary for any conditions, thereby saving fuel.

About the Circuit. The simple circuit of the Econometer is shown schematically in Fig. 1. The vacuum transducer, a proprietary device manufactured by Alphal Electronics, receives power from 5-volt regulator IC2 through current-limiting resistor R1. The output signal from the transducer is developed across R2, which is also connected to the stable 5-volt source.

The transducer mounts in the vacuum line from the carburetor. Its electrical output across R2 varies from 0.3 to 1 volt, depending on instantaneous manifold pressure. This voltage is applied to 10-step analog detector IC1.

The new integrated circuit used for IC1 contains 10 comparators and a reference-voltage network that detects the level of the analog signal at the input. Each comparator drives an open-collector transistor that is capable of sinking 40 mA at 32 volts. Since the comparators are arranged in a “totem pole,” as input signal level increases, the LEDs light in succession. Potentiometer R3 provides a means for setting the operating thresholds.

Construction. Because of the simplicity and noncritical demands of the circuit, any convenient board-type method of assembly—Wire Wrap, point-to-point on perforated board, or printed-circuit board—can be used. An actual-size etching-and-drilling guide for a pc board is shown in Fig. 2.

Mount the LEDs with their tops flush and their bottoms about 1/4” (6.2 mm) above the surface of the board, carefully observing polarity during installation. Then install the single jumper and two ICs, again taking care to properly orient them. Use of a socket for IC1 is optional, but if you do use a socket, try to find a
means of securing the IC (a dab of silicone rubber cement will do) so it will not vibrate loose.

Before mounting it in an enclosure, test the circuit board assembly. To do this, temporarily connect a jumper wire between the SNS (sense) point and GND (ground) in the circuit, apply 12 volts dc to the circuit, and check for a 5-volt dc reading between the junction formed by R1 and R2 and the ground bus. With R3 fully clockwise, all LEDs should light; turning the pot fully counterclockwise should extinguish all LEDs. Disconnect the dc power and remove the temporary jumper from the circuit.

Temporarily mount the circuit-board assembly in the enclosure in which it is to be housed. Carefully determine and mark the locations of the display and adjustment slot of R3 on the enclosure. Remove and temporarily set aside the circuit assembly. Then cut the display-window slot and drill a screwdriver access hole for R3. Drill another hole through the side or rear of the enclosure to provide entry for the wires that will interconnect the circuit with its transducer and the vehicle’s electrical system. Deburr all holes and glue a red plastic filter over the display window. Line the wire-entry hole with a rubber grommet if you are using a metal enclosure.

Installation. Five well-insulated color-coded wires, preferably 18-gauge stranded, are required to interconnect the Econometer with its transducer and the vehicle’s electrical system. Lengths of the wires are determined by the mounting location of the Econometer where it will be easily visible at a glance and the location of the engine’s vacuum hose. Starting from where the Econometer will be positioned and leaving several extra inches, route a black-insulated wire to a metal chassis connection or screw that is at chassis ground. Repeat this procedure with a red-insulated wire, this time terminating it at a source of fused +12 volts that is “live” only when the ignition is on. Connect and solder the free ends of the black and red wires to the GND and POS pads, respectively, on the circuit-board assembly. Identify on your schematic diagram the colors used for each function for future reference.

Locate a source of intake-manifold vacuum (usually a rubber hose near or on the carburetor) so that the transducer and its leads will not be near a moving part or engine heat. Using this as your reference point, route three wires with different color insulation (not red or black) back along the firewall, and into the passenger compartment under the dashboard. Continue routing to the Econometer’s case location, leaving several inches of slack at both ends of the wires before cutting to final length.

Now, working with only one wire at a time, strip away 1/4” of insulation from the first selected, slip on a 3/4” (19-mm) length of insulated tubing, and solder the wire to the terminal closest to the black dot on the transducer. Solder the other end of this same wire to the SNS pad on the circuit board.

Remove 1/4” of insulation from the second selected wire and connect and solder it to both center lugs on the transducer. Solder the other end of this wire to the GND pad on the board. Then, prepare the last wire in the same manner as for the first, including the insulated tubing, and solder it at one end to the remaining lug on the transducer (push the tubing down over both connections) and to the SRCE pad on the circuit board at the other end. Indicate your wire colors on your schematic.

**PARTS LIST**

<table>
<thead>
<tr>
<th>Part</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC1</td>
<td>TL490 10-step adjustable analog level detector (Texas Instruments)</td>
</tr>
<tr>
<td>IC2</td>
<td>78L05 5-volt regulator</td>
</tr>
<tr>
<td>LED1</td>
<td>Red -insulated wire, this time, strip away 1/4” of insulation from the first selected, slip on a 3/4” (19-mm) length of insulated tubing, and solder the wire to the terminal closest to the black dot on the transducer. Solder the other end of this same wire to the SNS pad on the circuit board.</td>
</tr>
<tr>
<td>R1</td>
<td>150-ohm, 1/4-watt resistor</td>
</tr>
<tr>
<td>R2</td>
<td>10,000-ohm, 1/4-watt resistor</td>
</tr>
<tr>
<td>R3</td>
<td>3000-ohm pc-type potentiometer</td>
</tr>
<tr>
<td>R4</td>
<td>330-ohm, 1/4-watt resistor</td>
</tr>
<tr>
<td>Transducer</td>
<td>MPT-50 (see Note below)</td>
</tr>
<tr>
<td>Misc</td>
<td>Enclosure: red plastic filter; color-coded stranded insulated wire (see text); insulated tubing; machine hardware; solder, etc.</td>
</tr>
</tbody>
</table>

Note: The following items are available from Alpha Electronics, P.O. Box 1005, Merritt Island, FL 32952 (Tel: 305-453-3534): Complete kit of parts less case and wire, for $28.00 plus $2 in US, $4 in Canada, $8 all other countries for postage and handling. Included in kit, but also available separately: No. PCI179 etched and drilled printed-circuit board for $3.50 in U.S. (add $2 for Canada, $4 for all other countries); No. MPT-50 transducer for $20 in US (add $2 for Canada, $4 for all other countries); TL-490 for $4.50 in US (add $2 for Canada, $4 for all other countries). Florida residents, please add 4% sales tax.

**Fig. 1.** The transducer converts vacuum level to a dc voltage. This is measured by level detector IC1 and displayed on a series of LEDs. More LEDs glow as the vacuum increases.
Bend the three-wire cable over the side of the transducer's case, taking care to avoid obstructing the small hole in the case, and secure with a cable tie. Now, cut the vacuum hose and install the transducer in series with the cut ends. (You can install the transducer in either direction.) After installation, make sure the connections to the transducer are airtight.

Position the three-wire cable so that it and the transducer do not contact any moving parts and are away from engine heat. Bundle the cable conductors together with cable ties and secure the assembly to the vehicle's chassis. Then assemble the project's enclosure.

**Checkout and Calibration.** Start your vehicle's engine and allow it to idle in neutral. Using a small screwdriver, adjust R3, through the small hole in the front of the enclosure, until four or five LEDs are on. Still in neutral, slowly press the accelerator and note that the display changes by one LED. Release and then quickly press and release the accelerator. At first, only one LED should be on for a second or so, four or five as the engine returns to idle.

In some vehicles, the vacuum connection is located above the throttle butterfly valves. If this is the case, slightly press the accelerator and adjust R3 to turn on only three LEDs. Completely releasing the accelerator should cause the display to have only one of the LED indicators lighted.

**In Use.** A quick glance at the Ecometer's display will suffice to keep you informed of your driving efficiency. The idea is to drive so that the maximum number of LEDs is glowing, indicating the highest vacuum and, consequently, the least fuel/burned. As you become familiar with the glowing display and accelerator position during driving, any marked change that persists in the display may indicate a problem in the operation of your engine.

One final note: “right foot awareness” has a great effect on driving efficiency and, thus, fuel economy. Using the Ecometer (or any other vacuum-measuring device) reveals how little accelerator pressure is needed to keep a vehicle moving at cruising speed with maximum vacuum. You may be surprised at how far you can back off the gas pedal before your vehicle slows down. So, when you get your vehicle up to the desired speed use a feather touch instead of a lead foot.
For best performance from operational amplifiers, special power-supply needs should be satisfied

OPERATIONAL-amplifier circuits almost always call for power sources that furnish clean, stable dc. Batteries are sources of good dc, but their expense relegates them principally to portable applications where commercial ac power is not readily available. The more economical solution to the problem of powering op amps is to use a power supply to convert commercial ac into smooth dc. In this article, we will examine several basic power-supply circuits that are well suited for use with operational amplifiers.

Symmetry is one of the principal characteristics required of most op-amp power supplies. Integrated operational amplifiers usually have two power-supply terminals—V+ and V−. If the voltages applied to these terminals are not symmetrical with respect to the input signal's ground potential (be it earth ground or an "artificial" ground), the output signal will ride on a dc level proportional to the power-supply asymmetry. This is usually undesirable—if a dc voltage is to be amplified, there will be error; if an ac voltage is to be amplified, capacitive coupling might be needed to prevent the upsetting of a subsequent stage's bias levels. Also, the possibility exists that the output signal will be asymmetrically clipped.

There are two basic types of power supplies that can be used with operational amplifiers—bipolar and single-ended. In a bipolar supply, positive and negative output voltages (usually equal in absolute value) are generated. The required symmetry arises from the fact that both the positive and negative supply rails are removed from ground by equal but opposite voltages. A single-ended supply generates only one voltage referenced to ground—either positive or negative. The ground of the power supply functions as one of the supply rails, and an "artificial ground" or "signal ground" is synthesized with a resistive voltage divider for reference purposes. This provides the required symmetry to the circuit.

Each type of supply has advantages and disadvantages. A bipolar supply furnishes a signal ground that is at true ground potential. This simplifies circuit design and eliminates at many points the need for capacitive coupling. However, a bipolar supply is more complex than a single-ended one and is more expensive to construct. A single-ended supply is simpler but usually makes the circuit to be powered slightly more complex. Let's examine some basic supplies of each type and see how they can be used to power op-amp circuits.

Basic Power Supplies. Appearing in Fig. 1 are simple single-ended (A) and bipolar (B) power supplies. In the single-ended supply, bridge rectifier D1 through D4 delivers pulsating dc to filter capacitor C1, which provides a smoothed dc output. Resistor R1 is a bleeder component. A voltage divider comprising R2 and R3 synthesizes an artificial signal ground at half of the positive dc output voltage (assuming R2 = R3) or approximately +17 volts. The op amp's positive power-supply terminal is connected to V+ and its negative supply terminal is connected to V−, which is actually true ground. An amplifier powered by this supply can process an ac signal symmetrically if the signal input is at artificial ground and the constraints of the power supply are not exceeded. The use of a blocking or coupling capacitor at the output of the amplifier permits the recovery of a pure ac signal with no dc component.

A basic bipolar power supply appears in Fig. 1B. The major differences between it and the single-ended supply just described lie in the transformer used, the need for a second filter capacitor, and the lack of a ground-synthesizing voltage divider. A transformer with a center-tapped secondary is needed. The bridge rectifier comprising D1 through D4 simultaneously charges filter capacitor C1 positively and C2 negatively. The ground at the output of the supply is connected to the transformer's center tap, and the positive and negative output voltages are symmetrical with respect to it. Note that the differential voltage between the positive and negative supply rails in each supply is the same even though the actual voltages on each of the rails with respect to true ground are not the same.

As a rule, operational amplifiers consume small amounts of current. This points to a disadvantage of the bipolar supply shown in Fig. 1B. Because only a small amount of output current is required, compact transformers rated at 300 mA or less are particularly attractive. Unfortunately, small transformers with center-tapped secondaries are not as widely available as ones lacking a center tap. The bipolar supply shown schematically in Fig. 2 offers a solution to this problem.
A glance at this supply reveals that it delivers positive and negative output voltages by means of a transformer lacking a center-tapped secondary. Also, note that the voltage rating of the secondary is half of that of the transformer shown in Fig. 1B. This supply can be thought of in one of two ways—either as two half-wave supplies, one positive and one negative with a common ground, or as a full-wave voltage doubler. In any event, it provides positive and negative voltages approximately equal to those produced by the supply shown in Fig. 1B. Also, the GROUND at the output of the supply is true ground, not an artificial one.

In practice, the true grounds of Figs. 1 and 2 are often connected to earth ground for shielding purposes. A fundamental difference between the bipolar supplies of Figs. 1B and 2 is that larger filter capacitors are required in the circuit shown in Fig. 2 for the same amount of ripple rejection. This is because the ripple frequency is lower (60 Hz as opposed to 120 Hz). Therefore, twice the capacitance is required if the capacitive reactance of the ripple shunt path to ground is to be kept at the same value as before.

**Electronic Filtering.** If the current drain from any of the power supplies that have been described is very low, and if the values of the filter capacitors are sufficiently large, only a small amount of ripple will be present in the dc output. However, in some applications even a low-level ripple component can be troublesome. An excellent safeguard against ripple is the use of electronic filtering such as that provided by a zener diode.

If a zener diode or similar component or electronic filtering network is connected to the output of a simple power supply, ripple can be almost entirely suppressed. The diode will provide not only the equivalent of several thousand or tens of thousand microfarads of filter capacitance in a very small space, but also a high degree of voltage regulation, which is very beneficial.

A basic electronic filter for positive-voltage applications is shown schematically in Fig. 3. When a positive unregulated voltage is initially applied to the input of the filter, capacitor Cl begins to charge up to the input voltage. Zener diode D1 clamps the voltage across the capacitor when the zener knee of its characteristic curve is surpassed. The voltage applied to the base of transistor Q1 is thus kept at a fixed level. This transistor effectively performs two functions. It multiplies the capacitance of Cl by its dc beta and behaves as an emitter follower, presenting a voltage at its emitter equal to the zener voltage less...
the forward voltage drop across the base-emitter junction. Capacitor $C2$ improves the performance of the electronic filter by helping to absorb transients. The time constant $R1C1$ results in a slow turn-on characteristic that eliminates potentially troublesome switching transients (clicks) from the supply rails.

The filter shown in Fig. 3 is designed for use with positive-output (negative-ground) single-ended power supplies. It can be adapted for negative-output applications by inverting the polarities of $C1$, $C2$, and $D1$ and employing a pnp instead of an npn pass transistor. The unregulated negative dc voltage would then be applied to the node $R1$-collector of $Q1$ and the regulated negative voltage would appear at the emitter of $Q1$. This technique is employed in the bipolar electronic filter shown schematically in Fig. 4. The top portion of this circuit is essentially the same as that shown in Fig. 3, and the bottom is a mirror image of the top—that is, a negative-output electronic filter.

**Practical Supplies.** A complete bipolar regulated power supply for op-amp audio applications appears schematically in Fig. 5. It is basically an amalgam of Figs. 2 and 4 with a few additional elements included. Hum and ripple components in its bipolar outputs are so low in level that they can be ignored in most applications, even where op amps are operating at high gain. The one precaution that is necessary is careful placement of transformer $T1$. This component should be located as far from high-gain stages as is practicable and it should be physically oriented to keep induced hum signals as small as possible.

Rectifiers $D1$ and $D2$ have forward current ratings of three amperes rms. This high current rating, together with the current-limiting action of $R1$, prevents damage to the diodes by excessive charging current to the capacitors when ac power is first applied to the supply. Actually, the inherent resistance of the 300-mA transformer secondary is great enough to prevent the initial charging current from damaging three-ampere diodes. However, if one-ampere diodes or a transformer with a larger secondary-current rating (and thus less winding resistance) are used, or both, it would be wise to include resistor $R1$ in the circuit.

The value of this resistor can be determined by measuring the resistance of the secondary and then solving Ohm's law for the resistance necessary to limit the current through the diodes to the rms rating. The peak voltage delivered by the secondary (1.414 times the rms voltage) should be used in this calculation, and the electrolytic capacitors should be considered dead shorts. Thus, only the inherent secondary resistance and any supplemental resistance provided by $R1$ will be available for current limiting. If the resistance value obtained by this calculation is larger than the resistance of the secondary winding, $R1$ should be included. Its value is simply the remainder obtained by subtracting the secondary resistance from the total resistance required. This results in a greater degree of protection for the diodes than is really necessary, but ensures trouble-free diode performance.

Note that 0.1-µF disc ceramic capacitors are shown in parallel with each rectifying diode. The function of these components is to suppress the spikes that are generated each time the diode junction breaks into and out of conduction. Fourier analysis of the waveform generated by the diode reveals the presence of significant high-order harmonic components. These harmonics can be troublesome to high-gain op-amp audio stages as well as a source of radio-frequency interference to AM or FM tuners.

Resistors $R5$ and $R6$ provide current limiting for zener diodes $D3$ and $D4$. Values of these components are best determined empirically after performing an initial calculation. First, the rated
zener voltage should be subtracted from the voltage appearing across C3 or C4. The remainder is the voltage drop across the current-limiting resistor. Then Ohm's law should be solved for that value of resistance that results in a current flow of two milliamperes through the resistance. Using this as a starting value, connect a suitable component to the rest of the circuit and temporarily connect a load resistor between the regulated output and ground. The load resistance should be such that the supply will be required to source two or three times the amount of current drawn by the op-amp circuit to be powered under worst-case (maximum current) conditions.

Apply power to the circuit and measure the voltage across the load resistor. Next, disconnect the load from the output of the supply and measure the open-circuit output voltage. If the difference between the loaded and unloaded output voltage is greater than a few percent at most, decrease the value of the current-limiting resistor to the next smaller commercial value and repeat the procedure. (Alternatively, employ a trimmer potentiometer in place of fixed resistors.) When the supply voltage has sufficient regulation, permanently install a fixed resistor of the next smallest commercial value with respect to the resistance value that has been empirically determined. This will provide an extra margin of voltage regulation.

The use of this empirical method, though somewhat crude, is justified by the fact that many experimenters purchase surplus zener diodes and transistors whose parameters might be unknown or considerably different from their rated values. Parameters such as a transistor's dc beta and the sharpness of a diode's zener knee will have a significant effect on the appropriate values of the current-limiting resistors. If this method does not produce the desired result, that is, if adequate voltage regulation cannot be obtained, either the zener diode or transistor (or both) should be replaced with another component of the same type. Deficiencies in either device can cause this problem.

Some readers might question the choice of the bipolar output voltage, ±8.4 volts, as opposed to the more common ±12 or ±15 volts. The author was more interested in extended, reliable op-amp performance than in large output-voltage swings. A lower supply voltage places less strain on an op amp and can also help prevent it from becoming noisy. The lower supply voltage does not affect stage gain. However, if a higher differential supply voltage is desired, simply use higher-voltage zener diodes for D3 and D4 and follow the same resistance-selection procedure that has already been outlined. Keep in mind that the output voltage will be approximately 0.7 volt less than the zener voltage of the diode and that decreasing the differential input-to-output voltage (VCE of the pass transistor) can degrade voltage regulation when large amounts of current are drawn from the supply. A ±8.4-volt prototype supply can simultaneously power four op-amp audio stages with fine regulation and lack of hum.

A complete single-ended supply for op-amp applications is shown in Fig. 6. It generates a regulated +12-volt output referenced to ground and employs a 100-PIV modular bridge rectifier and an integrated 12-volt regulator. Resistor R1 limits the surge current through the bridge during power-up. Capacitors C2 and C3 are disc ceramic components that should be placed close to the regulator IC package. Solid tantalum capacitors C4 improves the transient response of the regulator IC. Alert readers might have noted that no spike-suppressing capacitors are shown connected across the bridge's diodes. The capacitors might not be necessary, but any reader who plans to duplicate this circuit should leave space for them if actual performance indicates a need for them. Four capacitors would then be installed—one across each diode forming the bridge.

The +12-volt output is usually sufficient for most op-amp applications. It permits the output of an operational amplifier to swing almost 12 volts peak-to-peak without clipping. If a greater output swing is desired, a higher-voltage regulator IC and either a diode-capacitor voltage multiplier or a transformer with a smaller step-down ratio can be used.

Figure 7 is the schematic diagram of an op-amp audio amplifier that the author has powered with the single-ended supply just described. Resistors R2 and R3 form a voltage divider across the supply rails. The values of these components are identical (typically 100,000 ohms) so that the noninverting input of the op amp, the one to which input signals are applied via coupling capacitor C2, is at exactly half the supply voltage. This artificial signal "ground" potential permits the op-amp output to swing symmetrically in response to ac excitation. Components C1 and R4 decouple the supply line that feeds the biasing resistors to ensure good performance.

The bias level applied to the noninverting input of the op amp causes the output of the amplifier to remain at this same level during quiescence due to the effectively infinite dc feedback provided by R6. No dc amplification can occur, however, because C3 prevents any dc voltage division by R5 and R7. Resistors R1 and R7 provide dc return paths at the input and output of the stage.

The amplifier's voltage gain equals the quantity (1 + R6/R5) because the stage is noninverting. Selection of these resistor values is made to obtain the required voltage gain. The capacitance of C3 should be large enough that the component's capacitive reactance should be low at the lowest frequency to be amplified. One hundred microfarads or more should be sufficient for most audio applications, especially if the gain-determining resistances are on the order of kilohms or more.

Electrolytic capacitors C2 and C5 couple ac signals into and out of the amplifier, respectively. Their values have an influence on the frequency response of the amplifier. As a rule, the capacitance of C5 must be higher than that of C2 for a given cutoff frequency because the output impedance of the amplifier is much lower than the input impedance. Practical audio circuits of similar design commonly employ tens of microfarads or more capacitance for input coupling and hundreds or thousands of microfarads for output coupling. The optimum values for a given application depend on the lowest frequency to be amplified, the load impedance, etc.

Some audio circuits employing electrolytic capacitors and op-amps powered by bipolar supplies have appeared previously in the literature. These circuits have one principal disadvantage—there is no dc polarizing voltage impressed across the coupling capacitors. During one half of the ac signal cycle, the capacitors are reverse-polarized and a reverse current flow exists. At best, this can result in varying circuit impedances and shortened capacitor useful lifetimes. At worst, it can cause catastrophic capacitor failure and the application of dc levels from a previous stage to a subsequent one. In the op-amp circuit we have just described, all electrolytic capacitors are properly dc-polarized.

In Conclusion. Operational amplifiers are among the most useful devices available to the electronics experimenter. For best performance, their relatively modest power requirements should be satisfied through the use of stable sources of clean dc. To that end, a number of power-supply design ideas and practical circuits have been presented in this article. The experimenter can use them for guidance in the construction of power supplies that will enable him to derive the best possible results from his op-amp projects.
VOCAL ZAPPER
MAKES YOU A "SUPERSTAR"

Cancels the "phantomed" center channel of a stereo record and lets you substitute your own voice

BY CRAIG ANDERTON AND DAVID KARR

WHETHER to practice singing, have fun at parties, or just feel like a rock star, the Vocal Zapper may be just what you want. This inexpensive device lets you remove a lead singer's voice during playback of most stereo records and substitute your own voice. The Zapper is effective only with stereo records and most effective with those in which the lead vocalist (and bass instruments, if used) occupy center-stage, with vocal and nonbass-instrumental accompaniment mixed more toward the left or right of the stereo spread. (This type of mix is common in popular music.)

To create the center-channel effect, the sound engineer generally mixes equal amounts of in-phase lead-vocal (and bass) signal with the directional left- and right-channel signals. When a stereo record mastered in this manner is played back, the mix psychoacoustically places the lead vocalist stage-center, with accompanying voices and instruments to the left and right of the stereo spread.

In the ZAP mode, the Zapper subtracts the left and right stereo signals fed to its inputs in a differential amplifier. The result is that all common-mode (equal-amplitude, in-phase) signals in both channels—in this case, the lead vocalist—are cancelled out. What emerges from the amplifier and is fed back into the stereo system is a single mono signal with all the original left- and right-of-center information, including any reverb that may have been added to the lead vocal, but no lead vocal. The residual reverb will generally be of a low enough level to be unobjectionable if you replace the lead vocal with your own voice. In fact, you may even find it desirable, since it adds depth to the sound.

About the Circuit. The heart of the Vocal Zapper, shown schematically in Fig. 1, is differential amplifier IC1. This IC and microphone preamplifier IC2 can be an LM301, LM748, or any equivalent uncompensated operational-amplifier integrated circuit.

With S1 set to NORM, both the left input at J1 and the right input at J2 are mixed together and fed to the negative, inverting input of IC1. Since in this mode only one input of IC1 has a signal applied to it, no differential amplification occurs. In this event, IC1 simply passes all the signal information, including common-mode vocal in mono form, to both J3 and J4, the left and right outputs, respectively. If a microphone is plugged into J3 in the NORM mode, its signal would be amplified by microphone preamplifier IC2 and mixed with the left and right input signals to provide a "duet" signal capability. (Microphone gain is set as desired with potentiometer R11.)

Setting S1 to ZAP (common-mode cancel) causes the left-channel input signal to feed the positive noninverting input of IC1, while the right-channel signal continues to feed the negative input. Once the two signals enter IC1, one of them is inverted (phase shifted by 180°) so that common-mode information cancels. The music at this point would be lower in volume than in the NORM mode. During zapping, you can add your own voice in place of the vocal being cancelled simply by singing into a microphone.

Power for the circuit is supplied by a pair of 9-volt transistor batteries, B1 and B2. Since the circuit requires a bipolar source, B1 and B2 are ar-
Fig. 1. Schematic diagram of the Zapper. IC1 and IC2 can be any uncompensated op amp ICs similar to the LM301.

Fig. 2. Actual-size full pattern for a pc board is at right; component layout above.

**PARTS LIST**

- **B1, B2** — 9-volt transistor battery
- **C1, C2** — 15-pF disc capacitor
- **C3** — 0.01-µF, 15-V disc or Mylar capacitor
- **C4, C5** — 0.22-µF, 15-V disc or Mylar capacitor
- **C6** — 1-µF, 15-volt electrolytic or tantalum
- **C7, C8** — 10-µF, 15-volt electrolytic or tantalum
- **IC1, IC2** — LM301, LM748 or equivalent op amp (see text)
- **J1 through J4** — Phono jack (see text)
- **J5** — Microphone jack (see text)

Unless otherwise specified the following are 1/4-watt, 10% tolerance fixed resistors:

- **R1, R2, R3** — 1 kΩ
- **R4** — 22 kΩ
- **R5, R6, R7** — 47 kΩ
- **R8** — 68 kΩ
- **R9, R10** — 100 kΩ
- **R11, R12** — 100-kΩ upright pc-type trimmer potentiometer
- **R13, R14, R15** — 470 kΩ
- **S1, S2** — Dpdt switch

Misc. — Printed-circuit or perforated board; IC sockets (optional); sheet aluminum for front and rear panels; L brackets; No. 6 machine hardware; dry-transfer lettering kit; hookup wire; solder; etc.

**KIT ORDERING INFORMATION**

The following is available from PAIA Electronics, Inc., P.O. Box 14359, Oklahoma City, OK 73116: complete kit of parts No. 6730K, including front panel for $24.95 plus $3 postage. Also available separately: pc board No. 6730pc for $9.95. Add $5 handling charge for foreign orders.
ranged to supply ±9 volts, referenced to signal ground.

**Construction.** The Zapper is best assembled on a printed-circuit board (see Fig. 2) or perforated board with solder clips. In either case, sockets are optional, but recommended, for IC1 and IC2.

Mount the resistors, capacitors, trimmer potentiometers, and ICs (or their sockets) as shown in the component-placement guide. Don't forget to install the two jumpers at the locations labelled J. You have the option with J1 through J4 of using either right-angle pc-mount jacks (see Fig. 3) or standard panel-mount jacks.

Referring to the lead photo, prepare a front panel to accommodate power and NORM/ZAP switches S1 and S2 and mic jack J5 and to provide access to CANCEL TRIM and MIC GAIN controls R12 and R11. (Note: Select a jack that mates with the connector on the microphone you plan to use with the Zapper and drill a hole just large enough to accommodate it.) Then mount the panel to the pc assembly edge with the letters A through E on it with a pair of small L brackets.

Loosely twist together two lengths of different colored insulation hookup wire or substitute a length of shielded cable and solder one end to the lugs on the mic jack. Being careful to maintain proper polarization, connect and solder the other end of the twisted pair or shielded cable to points M (hot) and G (signal ground) on the pc board. This step and the remainder of off-board wiring are shown in Fig. 4.

**Installation and Use.** Snap a pair of batteries into their connectors, but leave the power switch off. Then connect the Zapper into your stereo system's TAPE OUT/TAPE MONITOR loop. From now on, when you wish to use the Zapper, all you do is activate the receiver or amplifier tape-monitoring function.

After installation, turn on power first to the Zapper and then to the stereo system. Set your stereo system's input selector to PHONO but leave the TAPE MONITOR switch in the out position. When you play a stereo record, you should now hear normal stereo sound. Set the Zapper to NORM and switch in the stereo system's tape-monitor function. The stereo spread should now disappear and be replaced by mono sound. You might also note a slight drop in overall volume.

Now switch to the ZAP mode and listen to the sound. The lead vocal should be absent, but the stereo spread should remain. If you can hear the lead vocal (don't confuse this with any reverb that may have been added), adjust the CANCEL TRIM control for maximum cancellation, which should occur somewhere near the center of the pot. The CANCEL TRIM control need not be touched again.

Once the Zapper is operating properly, plug headphones into the amplifier and then a microphone into the Zapper. (Don't attempt to listen through speakers with a live microphone. If you do, acoustic feedback can damage your system.) As you sing into the microphone, adjust the MIC GAIN control for the proper blend between microphone and program material. At first, you might tend to set mike gain too high, which could result in distortion. With a little practice, you'll soon be using the MIC GAIN control with the proper "touch."
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PROTECT YOUR PROPERTY
WITH A
CMOS GUARDIAN

By John D. Richard

Wouldn't it be nice to have a device that would tell you when someone has operated any line-powered electrical device in your home or office without your permission? Well, the Sentinel described here does just that. Once coupled to any 117-volt ac line-operated equipment or lighting circuit, the Sentinel constantly monitors the ac power. To determine if the ac circuit has been switched on since the last time you checked, you simply push a button. No telltale lights or alarms sound when unauthorized use occurs; to find out, you must close a switch.

About the Circuit. Although IC1 in the illustration contains four 2-input NAND gates, the two inputs of each gate are wired in parallel to form four inverters. Gates A and B are wired in a set/reset flip-flop configuration.

A low input to gate B generates a high condition at its output. Because this signal is also present at the input of gate A, its output is forced low. The circuit is completed by feeding the low output of gate A to the input of gate B.

Output current from gate A is limited by R3 during changeover.

The high output from gate B is also routed to the input of gate D, forcing the latter's output, which is connected to LED1, low. The low output from gate A is inverted by gate C whose output, connected to LED2, goes high. Hence, if S3 is pressed (closed) at this time, only LED2 (which is green) can come on. If the input to gate B is forced high, the flip-flop changes states. Now only LED1 (red) can come on when S3 is pressed.

Momentary application of power from the ac line produces enough dc voltage for the flip-flop to change states. When the ac is removed, R1 discharges C1, but D2, now reverse biased, keeps the flip-flop from changing states. Once tripped, the circuit does not go into automatic reset.

Once S2 is pressed to reset the Sentinel, operating S3 will cause only the green LED to come on. If you press S3 later and the red LED comes on, someone has applied ac power to the device being monitored. Both ac-line and 9-volt dc power can be disconnected from the sentinel by opening S1.

Construction. Although the Sentinel can be assembled with just about any wiring technique, it is best assembled on a piece of perforated board or a printed-circuit board of your own design. Component placement and orientation, wire routing, and lead dress are not critical. Just arrange the circuit neatly. Then house it in an appropriate-size box that is predrilled for the three switches and two LEDs.

In normal state of flip-flop IC1/IC2, LED2 glows when S3 is pressed.
If flip-flop is toggled, LED1 glows.

B1—9-volt battery
C1—1-µF polyester capacitor
D1, D2—1N4002 diode
IC1—4011 quad 2-input NAND gate
LED1—Red light-emitting diode
LED2—Green light-emitting diode
R1, R3—220,000-ohm 1/4-W 10% resistor
R2—10,000-ohm, 1/4-watt 10% resistor
R4—1000-ohm, 1/4-watt, 10% resistor
S1—Dpdt switch
S2, S3—Normally open pushbutton
T1—6.3-V transformer
Misc.—9-volt battery and holder, suitable enclosure, machine hardware, line cord, hookup wire, etc.

In the flip-flop's "normal" state, with no power applied to T1, closing S2 places the flip-flop in the state where only LED2 can light when S3 is pressed.

The primary of T1 connects to either the power line or the primary of the power supply (after the power switch) of the device to be monitored. If T1's primary is energized, the C1/D1 circuit creates a positive voltage that is applied to the input of gate A via current-limiting resistor R2. When this voltage exceeds the switching level of gate B, the flip-flop changes states. Then, pressing S3 causes LED1 to light.
Audio
Time Delay System

A Low-Cost Analog Audio Delay Line

BY JOHN ROBERTS

Analog system employs a bucket-brigade device and compansion to provide adjustable delays and wide dynamic range

THE AUDIO BUFF is constantly seeking ways to make the sound from his audio system more realistic. That's why there's been a high level of interest in a family of audio components known as audio delay lines or "room expanders." Such a component is intended to create an auditory illusion that simulates the environment in which music is ordinarily performed—a large concert hall, a night club, etc.—rather than the sense of being reproduced in a small listening room. To provide you with a component that will achieve this objective with any hi-fi system, we present here an analog audio delay line, that can be built by a technically inclined audiophile for a relatively moderate cost. The delay line described is analog in design.

THE analog audio delay line described here employs a high-performance, "bucket-brigade" analog shift register and a 2:1 compansion system to preserve as much of the input signal's dynamic range as possible. According to its designer, it offers an adjustable delay time of from 5 to 68 ms, a frequency response of 30 to 12,000 Hz (+0, −1 dB), an output noise rating ("A" weighted) of −91.5 dBm at 5 ms delay, and a THD + N content of 1% at 10 kHz. A complete stereo delay-line kit including an ac or dc power supply and a custom enclosure is available for $250.

Delay Lines and Reverberation. Perhaps the most significant difference between a large concert hall and the typical home listening room lies in their reverberation times. Reverberation time can be defined as the amount of time it takes for a steady-state sound field to decay to −60 dB relative to the level that existed before the sound source was deactivated. The size of a room and the materials used to construct it affect its reverberation time.

Because the speed of sound in air is relatively constant (approximately one foot or 0.3 meter per millisecond) for given atmospheric conditions, sound waves travelling in a very large room will experience fewer energy-absorbing collisions with the walls, floors, and ceiling per unit time than will similar sound waves travelling in a small room. Accordingly, sound waves in the large room decay less rapidly.
A listener in a reflective room receives a series of sound waves starting with the wave that reaches him on a direct path from the source. The reflected waves arrive at some time after the direct signal. The human ear derives from these differences in arrival times clues as to the size of the listening space.

When the reflections arrive so soon after the direct wave that they merge with it, the room "sounds" small. By contrast, larger differences in arrival times and more protracted reverberation tell the listener that he is in a large hall.

In operation, an audio delay line accepts signals from the main audio channels, stores them for a given amount of time, and then presents them to a power amplifier which drives one or more speaker systems. The speakers driven by the main-channel signals are placed in front of the listener, and the speaker(s) driven by the delayed information is (are) placed behind him or off to the sides. The goal is to synthesize the reverberative characteristics of the type of environment in which the recorded program material would ordinarily be performed.

**Delaying the Signal.** Various means, electromechanical and electronic, are available for providing delayed signals; but cost, complexity, and space requirements make most of these impractical for use in the home. It seems fair to say that use of delayed signals to enhance home music reproduction was brought about by the availability of purely electronic delay systems.

State-of-the-art reverberation synthesizers derive suitable audio delays by means of analog or digital shift registers. In either method, the audio signal is divided at a given rate into samples that describe its instantaneous amplitude. These are sequentially deposited in a shift register that stores them for a given amount of time. The samples are clocked through the register, the end of which is connected to a circuit that reconstructs a smoothly varying analog signal out of the series of discrete samples applied to it.

The difference between analog and digital delay lines lies in the manner in which the input signal is sampled, stored, and reconstructed. In an analog system, the input signal is sampled and its instantaneous amplitude is applied to the input of an analog shift register. What happens next depends on the type of analog shift register that is employed.

If the register is a bucket-brigade de-
vice, the sampled voltage charges a small input capacitor. This charge is then transferred to the first of a long series of storage capacitors by means of a voltage-controlled switch (a FET driven by one component of a two-phase clock). Next, a new sample charges the input capacitor and the first sample is transferred to the second in the string of storage capacitors. The sample in the input capacitor is then transferred to the first storage capacitor; the input capacitor receives a new sample, the sample in the second storage capacitor is transferred to the third while that in the first is transferred to the second, and so on.

This process goes on continuously and the analog samples of the input waveform make their way down the bucket-brigade device in the form of packets of charge being shifted from one capacitor to the next. At the end of the register, a low-pass filter integrates the staccato sequence of samples delivered to it into a smoothly varying replica of the input waveform.

The second type of analog shift register, the charge-coupled device, functions in a similar manner but employs a different method of storing and transferring the analog samples of the input waveform. Instead of using actual capacitors to store the charge packets, a charge-coupled device or CCD employs the equivalent capacitances of a series of MOSFET channels that form under gate structures biased by voltages greater than the MOS threshold.

The MOS elements of a CCD are close enough to each other that the free charge consisting of minority carriers stored in the inversion layer associated with one MOS capacitor (the channel) can be transferred to the channel region of the adjacent device. The transfer of charge is governed by the multi-phase clock voltages applied to the gate structures of adjacent MOS devices. In a CCD, an analog sample of the input signal is stored as a channel charge. Because CCD gates are very small (typically a few square micrometers in area), tiny amounts of charge are involved—usually from approximately 10 electrons (!) to 10^5 electrons.

In an analog delay line, the amount of delay that is obtainable depends on both the rate at which the samples are clocked through the shift register and the number of storage elements in the register. Current IC fabrication techniques have made possible the construction of BBD or CCD delay lines containing hundreds and even thousands of storage elements. Such devices offer delays as long as 100 milliseconds or more—longer than necessary for most reverbération synthesis applications.

The faster the clock frequency, the shorter the delay and, for a given device, the more closely the output signal resembles the input signal. As a rule, longer delays result in some loss of high frequencies and degradation of dynamic range. Advanced delay-line ICs offer impressive performance in spite of these limitations. For example, the Reticon SAD-4096 employed in the project to be described here has 2048 storage elements, a clock-frequency range of 8 kHz to 2 MHz, and a delay range of 1 millisecond (2-MHz clock) to 250 milliseconds (8-kHz clock). The dynamic range of its output is 65 dB when the clock frequency is a relatively low 20 kHz. The use of compansion can provide even greater dynamic range.

In a digital system, the input waveform is sampled at an appropriate rate. Each sample is applied to an A/D converter which transforms it into a sequence of bits describing its instantaneous amplitude in digital form. Each digital word describes a specific sample and is applied to either a digital shift register or to a RAM, depending on the design of the delay line. If a shift register is employed, the words are clocked through the register at a specific clock rate and eventually appear at its output. If a RAM is used, the words are written into specific memory locations, stored in them for a certain period of time, and then read out of the memory locations in the appropriate order.

As the digital words stream out of the register or are read out of the RAM, they are applied to the input of a D/A converter which changes them back into analog form. Low-pass filtering smooths out the reconstructed analog waveform. The total delay provided by a digital system depends on the length of the shift register and the rate at which data is clocked through it or on the size of the RAM and the rate at which digital data is written into and read out of it.

Some delay line designs employ delta modulation. That is, the input waveform is sampled continuously and compared to the previous sample. The circuit that processes the input waveform generates an output signal that describes the result of this comparison—whether the input signal has decreased or increased in amplitude, or remained constant. If this is done, only “change” information need be clocked through a register or written into memory, rather than information completely describing the instantaneous amplitude of the input signal at each moment that it is sampled. At the output of the storage circuit, a demodulator reconstructs an analog replica of the input waveform that is low-pass filtered to remove abrupt level changes introduced by the delta modulator.

**Design Considerations.** A digital system’s greatest advantage is that the signal degradation it introduces is fixed and independent of the length of the delay. Once a signal sample has been converted into digital form, it can be manipulated any number of times without loss. The quality of the output signal is affected only by the linearity and dynamic range of the A/D and D/A converters at the input and output.

The dynamic range of a digital system in which the digital words directly describe the corresponding input samples is approximately 6 dB per bit. A 16-bit linear digital system thus offers a dynamic range of approximately 96 dB, but is horrendously expensive. To obtain an acceptable dynamic range using fewer bits, various “nonlinear” coding schemes have been developed.

Analog delay systems bypass the complexities of A/D and D/A conversion but degrade signals more as delays become longer. Because analog shift registers are
audio delay

The length of delay required depends on the reverberation times that the designer is attempting to synthesize. In the author’s opinion, audibly believable reverberation can be generated by feeding the output signal of the delay device back to the input. The resulting multiple repetitions simulate the arrivals of reflected sounds along paths of different lengths. In such a system, the reverberation time can be calculated from the length of the delay and the gain of the feedback loop. For example, if the signal is delayed 50 ms and the gain of the loop is $-3$ dB, it will take 20 recirculations of the signal before the output level decays to $-60$ dB relative to its initial amplitude.

The reverberation time is thus one second.

Natural-sounding reverberation can be achieved with a maximum shift-register delay of 40 to 60 ms as long as the recirculation of the signal does not produce an audible feedback signal.

The following, unless otherwise specified, are 1/4-watt, 5%, fixed carbon-composition resistors:

R1, R6, R7 — 1000 ohms
R2, R10 — through R15, R22, R31, R32, R34 — 100,000 ohms
R3, R36, R41 — 100,000-ohm, linear-taper potentiometer
R4, R25, R26 — 3300 ohms
R5 — 300,000 ohms
R8, R40 — 100 ohms
R9 — 75,000 ohms
R16, R17 — 22,000 ohms
R18, R35 — 68,000 ohms
R19, R20, R37, R38 — 43,000 ohms
R21 — 10 ohms
R23 — 36,000 ohms
R24, R27, R28 — 15,000 ohms
R29 — 62,000 ohms
R30 — 180,000 ohms
R31 — 20,000 ohms
R39 — 10,000-ohm, linear-taper potentiometer
S1 — Opdt pc-mount push-on/push-off switch
Misc. — Printed circuit board, IC sockets or Molex Soldercons, circuit board stand-off, control knobs, suitable enclosure, shielded patch cords, hookup wire, etc.

**PARTS LIST**

**DELAY CIRCUIT**

<table>
<thead>
<tr>
<th>Part</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C18, C19, C32</td>
<td>0.1 µF, 50-V disc ceramic capacitor</td>
</tr>
<tr>
<td>C2 — 100 µF, 16-V radial-lead electrolytic</td>
<td></td>
</tr>
<tr>
<td>C3, C13, C16, C25, C27 — 4.7 µF, 16-V radial-lead electrolytic</td>
<td></td>
</tr>
<tr>
<td>C4 — 0.01 µF, 5% Mylar capacitor</td>
<td></td>
</tr>
<tr>
<td>C5, C11, C21, C22, C24 — 100-pF, 5% polystyrene capacitor</td>
<td></td>
</tr>
<tr>
<td>C6, C7, C8, C12, C17</td>
<td>1-µF, 25-V radial-lead electrolytic</td>
</tr>
<tr>
<td>C9, C14 — 6-pF, 50-V disc ceramic capacitor</td>
<td></td>
</tr>
<tr>
<td>C10 — 2200-pF, 5% polystyrene capacitor</td>
<td></td>
</tr>
<tr>
<td>C15, C26 — 0.47-µF, 25-volt radial-lead electrolytic</td>
<td></td>
</tr>
<tr>
<td>C20 — 1000-pF, 5% polystyrene capacitor</td>
<td></td>
</tr>
<tr>
<td>C23 — 510-pF, 5% polystyrene capacitor</td>
<td></td>
</tr>
<tr>
<td>C28 — 0.0022 µF, 5% Mylar capacitor</td>
<td></td>
</tr>
<tr>
<td>C29, C30</td>
<td>470-pF, 50-V disc ceramic capacitor</td>
</tr>
<tr>
<td>D1, D2</td>
<td>1N914 diode</td>
</tr>
<tr>
<td>IC1 — CD4007AE dual complementary pair plus inverter</td>
<td></td>
</tr>
<tr>
<td>IC2 — CD4013AE dual D flip-flop</td>
<td></td>
</tr>
<tr>
<td>IC3 — SAD-4096 bucket-brigade analog shift register (Reticon)</td>
<td></td>
</tr>
<tr>
<td>IC4 — NE577N comparator</td>
<td></td>
</tr>
<tr>
<td>IC5 — TL074CN quad BFET op amp</td>
<td></td>
</tr>
<tr>
<td>J1, J2, J3, J4</td>
<td>Phono jacks</td>
</tr>
</tbody>
</table>

Fig. 2. Schematic diagram of the delay line. Two audio input channels are combined by IC5C into a single channel which is delayed by IC3.

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The bandwidth of the delay line and the rate at which its input signal is sampled are intimately related. Although standard high-fidelity practice would dictate a flat frequency response between 20 and 20,000 Hz, a narrower bandwidth is appropriate for a delay line. The principal reason for this is that natural reverberation generally causes high-frequency attenuation.

Sampling theory indicates that a signal must be sampled at least twice every period if it is to be reconstructed into continuous form without error. The sampling frequency thus should be at least twice that of the highest frequency in the signal. Furthermore, a rolloff caused by the reconstruction process itself results in a response 3 dB down at approximately one-third of the sampling frequency. (This rolloff is in addition to any due to a smoothing filter at the output.)

Any signal frequency greater than one-half of the sampling frequency will stimulate the production of aliases or beat tones that fold back into the useful passband. For example, if a 22-kHz signal is sampled at a rate of only 40 kHz, an alias will appear at 18 kHz. Accordingly, for all of the above reasons, it is good design practice to band-limit the signal to be sampled to about one-third of the sampling rate.

**About the Circuit.** The Analog Audio Delay Line appears in block-diagram form in Fig. 1 and schematically in Fig. 2. The block diagram shows the principal function stages of the project.

A voltage-controlled oscillator generates a train of pulses at a rate determined by the setting of the delay potentiometer. The oscillator drives a flip-flop which provides a two-phase clock signal by means of its complementary (Q and Q) outputs. This two-phase clock governs the transfer of signal samples within the analog shift register.

An op-amp input stage accepts signals from the two main stereo channels and generates either an L+R or L-R output, depending on the position of the MODE switch. A considerable saving in system cost and circuit complexity can be realized by combining the main stereo channels to form one channel of delayed information.

Summing the two main channels before delaying them results in a conventional monaural signal that is then delayed, amplified and reproduced by a single loudspeaker. The effectiveness of the L-R mode can be dramatically demonstrated by listening to a stereo FM broadcast. During the musical portion of the broadcast, relatively high levels of L+R or stereo reverboration can be introduced to provide a pleasing audio effect. When the announcer's voice is heard, it sounds as if he is talking from the bottom of a well. This can also happen when a centered vocal or instrumental soloist predominates.

The L-R mode, in which the direct center components are cancelled out, can prevent this from happening. An additional benefit provided by the L-R mode is realized because of the common mixdown practice of placing room or ambience microphones and studio reverberation unit output signals away from center. Although it is not possible to completely characterize the differences in sound quality provided by the two modes, the author's experience is that L-R reverberation sounds "softer" or more subtle. The type of music and the particular mix-down will determine which mode is more pleasing.

The signal from the input network is applied to a second-order active low-pass filter with a cut-off frequency of 15 kHz. This prevents foldback/aliasing problems that might otherwise occur. A 2:1 IC compressor acts on the filter output before it is applied to the analog shift register. Also applied to the compressor input is a signal component that is provided by the recirculation loop.

Delayed audio signals appearing at the output of the analog shift register are treated by a fifth-order active low-pass filter before being processed by a 1/2 IC expander. This filter smooths out the signal provided by the delay line and suppresses any ultrasonic clock energy contained in it. One portion of the expander output makes its way back to the compressor input by means of a recirculation loop. This loop comprises R36, the REDELAY potentiometer.

Complementary compression and expansion make it possible for the delay line project to have an impressive dynamic range. The rated S/N of the SAD-4096 analog shift register varies from more than 75 dB for its shortest delays to approximately 65 dB for its longest delay time. The compression employed in this project allows the delay system to have a very large dynamic range. As measured by the author, the IHF "A" weighted noise at the project's delayed output is -91.5 dBm at 5 milliseconds and -89 dBm at 100 milliseconds. Input-level adjustments are therefore unnecessary.

Output signals are presented to PAN control R39. This potentiometer allows the user to drive the subsequent stages in the signal chain with a fully undelayed audio signal (when the wiper is set to the DIRECT extreme of its travel), a fully delayed signal (when the wiper is set to the DELAYED extreme of its travel), or with a mixture of the direct and delayed versions of the input signal (when the wiper is set between the two extremes of its travel). Potentiometer R41 can be adjusted for the desired balance of front to back sound levels. (Continues on next page.)
Power Supply. The analog delay line project requires modest electrical power. Its basic requirement can be obtained from any single-ended supply capable of delivering 12 volts at 20 mA. This modest amount of power can be provided from the ac power line with the ac power supply LM301 operational-amplifier integrated circuit (IC1), which, in turn, governs the operation of a pass transistor (Q1). This pass transistor acts as the regulated source for the delay circuit. The dc supply can be used with virtually any unregulated source capable of delivering +12 to +30 volts dc. Again, LED1 serves as a convenient power-on indicator.

Construction. The use of printed-circuit construction techniques is strongly recommended. Full-size etching and drilling guides of suitable pc boards for the main

![Diagram](image)

shown schematically in Fig. 3. This supply employs a center-tapped step-down transformer (T1), a full-wave rectifier (D1 and D2), four capacitors (C1 through C4), and a 12-volt regulator integrated circuit (IC1). Light-emitting diode LED1 is a convenient power-on indicator.

In mobile and many other applications, however, a source of 117-volt sinusoidal ac power is not readily available. In such situations, the project can be powered by the dc power supply shown schematically in Fig. 4. This power supply employs a zener diode (D3) as a voltage reference for an

![Diagram](image)

Parts List

AC Power Supply

- C1—1000-µF, 25-V radial-lead electrolytic
- C2, C3—0.1-µF, 50-V disc ceramic capacitor
- C4—4.7-µF, 16-V radial-lead electrolytic
- D1, D2—1N4001 rectifier diode
- F1—1/4-ampere fast-blow fuse
- IC1—µA7812UC 12-volt regulator
- LED1—Light-emitting diode
- R1—1000-ohm, 1/4-watt, 5% fixed carbon composition resistor
- S1—Dpdt pc-mount push-on/push-off switch or spst toggle switch
- T1—20-volt, 250-ma center-tapped stepdown transformer (Signal Transformer Co. No. ST-420 or equivalent)
- Misc.—Printed circuit board; fuse clips; line cord; strain relief; circuit board standoffs; machine hardware; hookup wire; solder; etc.

Parts List

DC Power Supply

- C1, C5—0.1-µF, 50-V ceramic disc capacitor
- C2—100-µF, 16-V radial-lead electrolytic
- C3—4.7-µF, 16-V radial-lead electrolytic
- C4—100-pF, 50-V ceramic disc capacitor
- D1, D2—1N914 diode
- D3—6.2-volt, 1-watt zener diode (1N4735 or equivalent)
- F1—1/4-ampere fast-blow fuse
- IC1—LM301AN operational amplifier
- LED1—Light-emitting diode
- Q1—2N3906 npn silicon transistor
- The following are 1/4-watt, 5%, fixed carbon-composition resistors:
  - R1, R7—510 ohms
  - R2, R5—33,000 ohms
  - R3, R4—10 ohms
  - R6—33,000 ohms
  - R81500 ohms
- S1—Dpdt pc-mount push-on/push-off switch or spst toggle switch
- Misc.—Printed circuit board; fuse clips; strain relief; circuit board standoffs; hookup wire; solder; hardware; etc.
delay circuit, the ac power supply, and the dc supply appear in Figs. 5, 6, and 7, respectively. Component-placement guides for these boards appear in Figs. 8, 9, and 10. The main circuit board has been laid out to keep power and ground bus runs as short and direct as possible, and to prevent objectionable leakage of ultrasonic clock energy into the audio-frequency signal path.

Sockets or Molex Soldercons should be used when mounting ICs on the main circuit board, especially for IC3—any device costing that much deserves special handling. When mounting semiconductors and electrolytic capacitors, be sure to observe polarity and pin basing. Use the minimum amount of heat and solder consistent with the formation of good solder joints. Those components mounted off the board can be connected to it by means of suitable lengths of stranded, insulated hookup wire.

When assembly of the circuit boards is complete, carefully inspect them for cold solder joints, solder bridges between adjacent foils, reversed polarities, etc. Then interconnect the main board with the power supply board that has been assembled, using short lengths of stranded, insulated

Fig. 7. Etching and drilling guide for the dc power supply printed-circuit board.

Fig. 6. Etching and drilling guide for the ac power supply printed-circuit board.

Fig. 5. Full-size etching and drilling guide for the main printed circuit board.
hookup wire. Finally, mount the boards in a suitable enclosure, with spacers to insulate the boards from the metallic surfaces of the cabinet.

Adding It to Your System. Use shielded audio patch cords of appropriate lengths to interconnect the project with your existing audio system. The main stereo channels should be tapped at some point at which the signals are at line level. If the signals are tapped at the output of the preamplifier, the project’s output level potentiometer can be used as a front-to-back balance control. If the signals are tapped before the preamplifier’s volume control, the project’s output level potentiometer will have to be readjusted every time the level of the front channels is changed.

A single channel of delayed audio information calls for a monophonic power amplifier and one speaker system. However, the author’s prototype includes two output jacks wired in parallel so that both

Fig. 8. Component-placement guide for the audio delay line’s main pc board.

Fig. 9. Component-placement guide for the ac power supply of the project.

Fig. 10. Component-placement guide for the regulated dc-powered supply for the audio delay line.
channels of a stereo amplifier can be driven by the same signal if desired. The rear-channel amplifier can have a power rating as low as one-fourth that of the front-channel amplifier. Excellent performance has been obtained with as little as 20 watts of rated amplifier power for the rear channel.

Similarly, the speaker system associated with the rear channel need not be as sophisticated as those used in the main (front) stereo channels. Deep bass response and extended high end are simply not needed. A speaker system with clean midrange response and a power-handling capacity compatible with the rear-channel amplifier output power will suffice.

There are no “correct” delay-unit control settings. These adjustments should be guided by the type of music being reproduced and the personal taste of the listener. Also, the amount of reverberation that will have to be introduced to achieve a desired effect will depend on the individual recording of a given piece of music.

Two discrete delay channels can share a common enclosure and power supply. Such a configuration is available in kit form and can be connected to the main stereo channels in such a way that monaural addition or subtraction will not take place. If desired, one clock can be used to drive both stereo delay lines so that the delay times track each other. A richer sound may result if each channel has an independent, adjustable clock.

In Conclusion. Psychoacoustics is still as much an art as a science and remains a fertile field for experimentation. The analog delay line that has been presented here is designed with the adventurous, inquisitive audiophile in mind. It is, therefore, well suited for those readers who want to experiment with time-delay techniques.

KIT AND PARTS AVAILABILITY

The following are available from Phoenix Systems, 91 Elm St., Manchester, CT 06040: Complete kit of parts, including enclosure, for a single-channel, dc-powered delay line, No. P-25-DLC, for $145; complete kit of parts, including enclosure, for a single-channel ac-powered delay line, No. P-25-DL, for $150; complete kit of parts for two-channel ac- or dc-powered (specify) delay line, No. P-25-SDL, for $250. The following are also available separately from the same source: SAD-4098 bucket-brigade analog shift register IC, No. P-SAD-4096 for $40.00; etched and drilled main printed-circuit board, No. P-25-DB, for $8.00; NE570N compander IC, No. P-NE570N, for $4.50; Signal Transformer Co. No. ST-4-20 step-down transformer, P-94-T, for $6.50; etched and drilled ac power-supply printed-circuit board, No. P-25-PSB, for $5.00; dc power-supply board, No. P-25-PSBC, for $5.00; TL074CN high-performance quad bFET operational amplifier, No. P-TL047CN for $2.50; µA7812UC 12-volt regulator IC, No. P-7812UC, for $1.50; 100,000-ohm linear-taper, pc-mount potentiometer, No. P-100KB, for $1.00; 10,000-ohm, linear-taper, pc-mount potentiometer, No. P-10KB, for $1.00; push-on/ push-off pc-mount dpdt switch, No. P-2PDT, for $1.00. Add $1.00 handling charge for orders less than $10. All items postpaid within continental U.S. COD orders subject to $2.00 surcharge. Connecticut residents add state sales tax.

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HIGH-SPEED ELECTRONIC FUSE

"Blows" within microseconds to protect sensitive components

BY CHARLES M. LENNY AND CHESTER DAVENPORT

FUSES, in many cases, blow too slowly to prevent damage in solid-state circuits. Power transistors, which are prone to thermal runaway when passing excessive currents, are especially vulnerable to slow-opening fuses. The electronic "fuse" shown in the schematic is a basic crow-bar circuit that operates in a hundred microseconds or so—more than fast enough to save low-power transistors—and can safely handle load currents up to 60 amperes.

How It Works. When an overcurrent triggers SCR1 into conduction, base drive is diverted from series-pass transistors Q1 and Q2, which cut off and stop the flow of current to the load. Incandescent lamp I1 has about a 10-ohm resistance when cold, and drops very little voltage. When SCR1 fires, the lamp glows, and the filament resistance increases to about 100 ohms, minimizing the load on SCR1 and acting as an indicator to show that the circuit has tripped.

Potentiometer R3 establishes the desired trip current. When the current passing through R2 (and R1 when S1 is set to HI), exceeds the desired limit, transistor Q3 turns on. The resulting positive voltage generated across R5 turns on SCR1. Resistor R6 limits the SCR gate current to a safe value. Diode D1 permits operating the electronic fuse with an inductive load, removing any probability of punch-through of Q1 or Q2.

Construction. At 60 amperes, resistors R1 and R2 can dissipate 45 watts each and should be provided with suitable heat sinking. A similar heat sink should be used for Q1, Q2 and SCR1. These two heat sinks should be mounted on two exterior sides of the selected chassis. A socket for I1 can be mounted on top of the chassis. Input and output power connectors S1, and R3 can be mounted on an empty side as desired. The Solitron SDT96306 can handle 70 amperes at 325 volts. A 2N3055 that can handle 15 amperes at 60 volts is an acceptable substitute.

Calibration of R3 is performed by using various resistive loads to draw specific currents, with R3 adjusted so that the lamp glows when the specific current is reached. A dial plate on R3 is used to identify the calibration points. Remember that the trip current must be within the pass transistor's rating.

Since the SCR is powered by dc, once it fires it will remain in the conductive state until the applied dc voltage is removed. This can be done either by installing a series switch in either of the supply leads or by turning off the driving power supply.

PARTS LIST

<table>
<thead>
<tr>
<th>Part</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0.01µF disc capacitor</td>
</tr>
<tr>
<td>D1</td>
<td>1N5551 diode</td>
</tr>
<tr>
<td>J1</td>
<td>Through J4—5-way binding post, color coded</td>
</tr>
<tr>
<td>L1</td>
<td>100-W incandescent lamp</td>
</tr>
<tr>
<td>Q1, Q2</td>
<td>SDT96306 (70 amperes) or 2N3055 (15 amperes)</td>
</tr>
<tr>
<td>Q3</td>
<td>TIP32 or any silicon transistor</td>
</tr>
<tr>
<td>R1, R2</td>
<td>0.05Ω, 50-W resistor</td>
</tr>
<tr>
<td>R3</td>
<td>20Ω, 5-W potentiometer</td>
</tr>
<tr>
<td>R4</td>
<td>390Ω, 10-W resistor</td>
</tr>
<tr>
<td>R5</td>
<td>180Ω, 1-W resistor</td>
</tr>
<tr>
<td>R6</td>
<td>100Ω, 1-W resistor</td>
</tr>
<tr>
<td>S1</td>
<td>Spot switch</td>
</tr>
<tr>
<td>SCR1</td>
<td>2N685 or similar SCR</td>
</tr>
<tr>
<td>Misc</td>
<td>Suitable heat sinks (2), socket for I1, enclosure, terminal strips, mounting hardware.</td>
</tr>
</tbody>
</table>
Do-It-Yourself

LOGIC CHIPS

By Forrest M. Mims

IN THIS day of ultra-sophisticated semiconductor technology, large-scale and very-large-scale integrated circuits (LSI and VLSI respectively) containing hundreds or even thousands of logic gates have become commonplace. Nevertheless, examine any board containing one or more LSI or VLSI chips and you'll probably find an assortment of small- and medium-scale integrated circuits (SSI and MSI) with relatively few gates or flip-flops package.

Circuit designers have long wanted to combine in a few packages the relatively small number of gates and flip-flops required to support most LSI and VLSI chips. Custom ICs are usually out of the question because of their high price and long development time. And what happens if a design change is necessary?

Semi-custom integrated circuits are a better choice. These chips contain arrays of gates which have not been metalized. In other words, the gates are independent of one another since they've not yet been connected together electrically by a metalization pattern on the top surface of the chip. The customer tells the custom IC house how he wants the gates interconnected, and the gate chips are then metalized according to the customer's specifications and installed in DIPs.

This procedure is faster and cheaper than the custom IC route, but it's still relatively expensive since the customer usually must agree to buy a thousand or more chips. And as in the case of the custom IC, what happens if a design change is necessary?

A third alternative is the do-it-yourself logic chip. Included in this category are field programmable logic array (FPLA) and programmable array logic (PAL, a trademark of Monolithic Memories, Inc.) chips. These chips contain arrays of logic gates interconnected via the same kind of fusible links used to make programmable read-only memories (PROMs). By selectively applying high-current pulses to the programming pins of an FPLA or PAL, fusible links can be opened in various patterns to produce a customized integrated circuit.

The PROM is itself a versatile do-it-yourself logic chip since it can be used to implement any truth table for which it has sufficient inputs and outputs.

You can better understand the operation and compare the differences of PROMs, FPLAs and PALS by referring to Figs. 1, 2 and 3. They show the internal circuitry of ultra-simple, hypothet-

---

Fig. 1. A PROM of four two-bit words. The AND array is fixed; the OR is programmable.

Fig. 2. A hypothetical PAL of two four-bit words. It is a backward PROM since the AND array is programmable while the OR is fixed.

Fig. 3. An FPLA of two four-bit words. Both the AND and the OR are programmable.
cal versions of each of these three kinds of programmable logic arrays.

As is readily apparent from these figures, all three circuits contain an AND array followed by an OR array. The input word applied to the AND array can be considered an address, data word or bit pattern. In any case, the effect is the same since a particular input switches the output of one of the AND gates from low to high. The outputs then reflect whether or not connections are present at the junction of the output line from a selected AND gate and the input lines to the OR gates.

A solid dot at the intersection of two array lines means the connection was unalterably programmed when the chip was made. User programmable fusible links are indicated by small circles at intersection array lines.

In the PROM (Fig. 1), the AND array is permanently programmed or fixed while the OR array is program-
mable. The AND array in Fig. 1 is pro-
grammed to address in turn each of the AND gates from top to bottom according to a standard 00, 01, 10, 11 input sequence.

The PAL (Fig. 2) is a backward PROM since the AND array is pro-
grammable while the OR array is fixed. In real PALs the OR array is factory programmed to give some of the most commonly used logic functions.

The FPLA (Fig. 3) is the ultimate do-

Fig. 4. Pin outlines and internal block diagrams of the PAL family of chips.
it-yourself logic chip since both the AND and OR arrays are programmable. While this provides the highest degree of flexibility, in practice the FPLA is much more difficult to use and more expensive than either the PROM or the PAL. All three kinds of chips can be programmed using standard PROM programmers, but the programming procedure for the FPLA is at least twice as cumbersome since both the AND and OR arrays must be programmed.

Some PALS and FPLAs include flip-flops to store output states and feed results back to the inputs. This makes possible such functions as counting, shifting and sequencing.

PALS without flip-flops can perform virtually any task now accomplished with SSI and MSI logic chips up to and including a 4-bit arithmetic logic unit! In many applications a single PAL can replace up to ten SSI/MSI packages.

A clever feature of PAL chips is a data security fuse. After the PAL has been programmed, the security fuse is blown to disable the circuit's internal verification logic. This prevents the internal program from being read out by a potential copier, thereby making the chip proprietary.

The PAL concept was pioneered by John Birkner of Monolithic Memories, Inc., and that firm now makes a family of fifteen PAL chips with National Semiconductor as a second source. Figure 4 shows the pin outlines and internal block diagrams for all fifteen chips. As you can see, considerable flexibility is provided by this lineup.

Information about PALS and FPLAs is not too abundant. The best way to learn about them is to contact a Monolithic Memories or National distributor or representative. To obtain a copy of the excellent "PAL Programmable Array Logic Handbook" published by Monolithic Memories (1165 E. Arques, Sunnyvale, CA 94086), Signetics of P.O. Box 9052, Sunnyvale, CA 94086) is a major maker of FPLAs. Their "Bipolar and MOS Memory Data Manual" contains FPLA data sheets and related information. Two Signetics engineers, Napoleon Cavlan and Stephen J. Durham, have written an excellent two-part article of the subject of the following:

For Electronics (July 5, 1979, pp. 109-114 and July 19, 1979, pp. 132-139). In an article for Computer Design (April 1980, pp. 141-147), Mr. Durham described a complete 60-character keyboard encoder complete with key bouncing and made from a single Signetics 825105 FPLA.

You can find the aforementioned articles in any good public or university library. For manufacturer's literature, check the yellow pages and call local electronics distributors or reps. If they can't help you, ask for the phone number of an authorized rep in your city or state. If necessary, call the company direct. The cost of a few long distance calls may be well worth the results you'll harvest.

Do-it-yourself logic chips require careful design procedure and a PROM programmer so they're not necessarily suited for the typical hobbyist or experimenter. But if you want to greatly simplify a favorite logic circuit while learning about one of the latest trends in digital circuit design, get your hands on some manufacturer's literature and warm up your PROM zapper.
HAS a television commercial ever made you feel like shooting your receiver? Now you can "blow away" commercials without destroying the TV set. The AD*ZAP TV Commercial Killer presented here employs "bullets" of infrared light to kill the sound and/or picture during an annoying advertisement. The project is relatively simple and can be connected to virtually any television receiver with only minor work.

When assaulted by an undesirable commercial, the viewer points a remote transmitter (which can be assembled into a plastic toy pistol or a standard case) at a small photoelectric receiver attached to the TV set and momentarily closes a switch. The transmitter thereupon emits an infrared signal that silences the sound and causes the receiver to start its selectable timing interval (30 or 60 seconds). If a second infrared signal is received during the timing interval, the TV picture tube is darkened. At the end of the interval, normal television-receiver operation is automatically restored. Receipt of a third infrared pulse before the timing interval ends will restore normal TV operation. Since the TV receiver remains powered and in sync during the timing interval, the picture returns without rolling or tearing.

The transmitter is a small, self-contained, battery-powered wireless unit. Its companion receiver is housed in a small metallic enclosure that is generally positioned atop the TV set. The AD*ZAP receiver is powered by a small wall-mount transformer and is connected to the rear panel of the television receiver by means of a multi-conductor cable of convenient length. Disconnecting the AD*ZAP receiver from the TV set leaves the TV fully ready for normal operation.

**About the Circuit.** The schematic diagrams of two versions of the AD*ZAP transmitter are shown in Fig.1. At A is the transmitter circuit designed for installation in a plastic enclosure approximately the size of a pack of cigarettes.
The circuit shown at B is almost identical and is designed to be mounted in a plastic-body six-shooter similar to the type used in some electronic target-practice games.

When switch S1 is closed, battery power is applied to the astable multivibrator comprising 555 timer IC1 and associated components. The multivibrator begins to oscillate and, when the output pulse causes pin 3 of IC1 to be low (about 25% of the time), high-level current pulses flow through infrared emitter LED1. The LED radiates bursts of infrared at a rate of approximately 3.2 kHz. The exact pulse rate is determined by the setting of trimmer potentiometer R2. Capacitor C3 ensures that enough current is available to the circuit during the time that LED1 is conducting.

The schematic diagram of the AD*ZAP receiver is shown in Fig. 2. Pulsed infrared from the transmitter causes phototransistor Q1 to turn on and off at around 3.2 kHz. Before infrared signals reach the phototransistor, they pass through an optical bandpass filter that attenuates much of the incident visible light that would otherwise affect the operation of Q1.

Voltage pulses developed across the phototransistor are amplified 60 dB by ac-coupled amplifiers IC1F and IC1E. These stages, as well as the high-Q, active state-variable filter that follows (IC1A, IC1B, IC1C), are part of a CD-4069 hex inverter. Although this CMOS chip is usually employed in a nonlinear operating mode, it is used here as linear amplifier inverter gates, much as low-gain op amps.

Also employed in this fashion is unity-gain buffer amplifier IC1D. This buffer supplies filtered pulses to the detector comprising C6, C7, D1, D2, and IC3A. Diode D1 is a biased clamper that limits negative excursions of IC1D's output to a level determined by the setting of THRESHOLD potentiometer R16. Half-wave rectifier D2 passes pulsed positive dc to filter R17C7. After approximately 10 milliseconds, the voltage across C7 increases to a level sufficient to trigger the Schmitt trigger—IC3A, R19, and R20. The output of IC3A thus goes to logic 1 when an infrared pulse reaches phototransistor Q1. Gate IC3A, together with C8, R21 and R22, also acts as a debouncer that generates a clean logic pulse when manual control switch S1 is closed.

The output of IC3A is applied to dual D flip-flop IC2. This chip is wired to function as a 3-counter. The first pulse applied to it causes pin 1 of IC2A (the Q output of the first flip-flop) to go to logic 1. As a result, relay driver Q2 receives base drive from gate IC3D via R29 and begins to conduct. Relay K1 interrupts the circuit between the audio output stage of the TV set and the TV loudspeaker, and SOUND OFF indicator LED1 begins to glow. Also, the logic-1 output of gate IC3D is inverted by IC4A, and the output of this NAND gate brings the reset input of multi-stage counter IC5 to logic 0. The counter then begins to tally the 60-Hz pulses.
that are derived from the ac power line, filtered by passive network C2R34, and squared up by Schmitt trigger IC3B.

If a second pulse appears at the output of IC3A due to either the receipt of another burst of infrared or a closure of switch S1, the Q output of IC2A (pin 1) returns to logic 0 and the output of IC2B (pin 13) goes to logic 1. The output of IC3D remains at logic 1, keeping Q2 in saturation, but Q3 begins to receive base drive from the Q output of IC2B via R26. As a result, relay K2 becomes energized and PICTURE OFF indicator LED2 begins to glow. The relay contacts are connected to the nodes of the television receiver's brightness-determining circuit. Closure of contacts D and F causes the screen to darken.

Both relays remain energized until either a third burst of infrared is received, switch S1 is closed, or counter IC5 has tallied 1800 pulses for a 30-second delay or 3600 pulses for a 60-second delay, depending on the setting of S2. If the counter runs through its cycle undisturbed, it will reset itself via IC4B and IC4A and will reset IC2A and IC2B via IC4B, IC4A, and IC3C. Both relays will then be deenergized and normal television reception will be reestablished.

The counting cycle can be interrupted and the relay(s) deenergized at any time by a closure of S1. Passive components C9 and R24 generate a 100-millisecond pulse when power is first applied to the circuit. This pulse is routed to the reset inputs of IC2A and IC2B via IC3C and ensures that both flip-flops are properly initialized and the relays deenergized in spite of any turn-on transients.

Power required by the AD*ZAP receiver is furnished by the simple supply shown in the lower right corner of Fig. 2. Unregulated dc provided by bridge rectifier D3 through D6 and filter capacitor C11 powers the relay and LED indicator circuits. The CMOS logic ICs are powered by +5 volts regulated, which is furnished by integrated regulator IC6. This particular supply voltage was chosen for the CMOS ICs because such circuits when operated in the linear mode exhibit higher gains at lower supply voltages.

Construction. The use of printed-circuit construction techniques is recommended. Suitable full-size etching and drilling guides for the two versions of the AD*ZAP transmitter are shown in Figs. 3A and 3B. The receiver pattern is shown in Fig. 4. The full-size etching and drilling guide of the circuit board that accommodates relays K1 and K2 and protective diodes D7 and D8 appears in Fig. 5. This latter board should be mounted inside the TV receiver's cabinet. Corresponding component-placement guides for these boards appear in Figs. 6A, 6B, 7, and 8.

Most components mount directly on the boards or via sockets. Exceptions include phototransistor Q1, resistor R1, and plug-in wall transformer TI. To suppress feedback-induced oscillations, one end of R1 is connected directly to the base lead of Q1. The other end of R1 and the collector and emitter leads of Q1 are connected to the appropriate pc foil pads via short lengths of insulated hook-up wire. Similarly, LED1 and LED2 are connected to the board with insulated hook-up wire.

It is good practice to install lengths of spaghetti or heat-shrinkable tubing on the exposed leads of all components that are mounted off the board to prevent accidental short circuits. The AD*ZAP receiver circuit board must be housed in a metallic enclosure.

Substitutions should not lightly be made for phototransistor Q1. For the device specified and the parameters of the circuit shown in Fig. 2, the phototransistor should function in the linear portion of its response curve for ambient light levels of up to 50 foot-candles of incandescent light or 150 foot-candles of daylight. Sensitivity of the device specified can vary over a 7:1 range. Therefore, the circuit incorporates means to compensate for such sensitivity variations. For example, it may be necessary to change the value of resistor R3 or to even substitute another phototransistor of the same type. (Note that photodarlingtons have too much gain and will, therefore, not
RECEIVER PARTS LIST

C1, C3 — 0.0047-μF disc ceramic capacitor
C2, C10 — 0.01-μF disc ceramic capacitor
C4, C5 — 0.001-μF, 5% tolerance Mylar or polystyrene capacitor
C6, C7, C8, C9, C12, C13 — 0.1-μF disc ceramic capacitor
C11 — 100-μF, 25-volt axial-lead aluminum electrolytic
diode
D12 — IN370 or equivalent germanium diode
D3 through D6 — 1N4001 rectifier
D7, D8 — 1N914 or 1N4148 silicon switching diode
IC1 — CD4069 hex inverter
IC2 — CD4013 dual D flip-flop
IC3 — CD4071B quad 2-input OR gate (device must have B suffix)
IC4 — CD4012 dual four-input NAND gate
IC5 — CD4040 12-stage binary counter
IC6 — LM78L05 5-volt, 100-mA regulator
K1, K2 — Spdt relay with 12-volt dc, 1400-ohm coil (Guardian No. 1345-IC-12D or equivalent)
LED1 — Yellow light-emitting diode
LED2 — Red light-emitting diode
Q1 — FPT-100 phototransistor (Fairchild)
Q2, Q3 — 2N2222 npn silicon switching transistor
The following, unless otherwise specified, are 1/4-watt, 5% tolerance, carbon-composition fixed resistors.
R1, R20 — 10 MΩ
R2, R16 — 10-kΩ linear-taper, horizontal pc-mount trimmer potentiometer
R3, R26, R29 — 4.7 kΩ
R4, R6 — 10 kΩ
R5, R7, R23 — 220 kΩ
R8 — 15 kΩ
R9, R12 — 150 kΩ
R10, R11 — 30 kΩ, 1%-tolerance, 1/4-watt, metal-film
R13, R14, R17, R22 — 100 kΩ
R15, R16, R24, R25, R32, R33, R35 — 1 MΩ
R19, R21, R34 — 470 kΩ
R27, R30 — 47 kΩ
R28, R31 — 680 kΩ
R36 — 3.3 MΩ
S1 — Spdt, normally open, momentary-contact pushbutton switch
S2 — Spdt miniature slide switch
T1 — 12-volt ac, 100-mA wall-mount plug-in transformer
Misc. — Printed circuit board, suitable metallic enclosure, LED mounting collars, grommets, infrared bandpass filter (see note below), heat-shrinkable tubing, hookup wire, solder, pc standoffs, suitable hardware, etc.

Note 1 — Pushbutton switch S1 is a Panasonic No. EVQ-P1R component that is available from Digi-Key, Box 677, Highway 32 South, Thief River Falls, MN 56711.

Note 2 — There are several possible items that can be used as an infrared bandpass filter. The author used a 1/4-inch circular piece of Eastman Kodak Wratten No. 98B gelatin filter. Kodak advises that a piece of unexposed but processed Kodachrome slide film can also be used, as it blocks visible light almost completely but is transparent to infrared. Gelatin Wratten filters measuring 2 inches square are available from Eastman Kodak dealers for approximately $5.00 each.

Fig. 2. Schematic diagram of the AD*ZAP receiver.
The phototransistor should be mounted on the front panel of the AD-ZAP receiver's enclosure. The device specified just fits a standard 0.200-inch (Jumbo) LED mounting collar.

An infrared optical filter is mounted in front of the phototransistor's aperture. Use black silicone cement or some similar opaque material to ensure that no light can leak in behind the filter. The two indicator LEDs can also be mounted on the receiver enclosure's front panel. To facilitate interconnection of the receiver circuit and relay board, a multiconductor connector should be mounted on the enclosure.

For convenience, the author mounted his relay board inside the television receiver with which the AD-ZAP system was to be used. If you plan to use your system with more than one TV set, a separate relay board can be used in each. You can substitute the relays specified so long as their coils are rated at 12 volts dc and have resistances of 400 ohms or more. If a dpdt relay is employed for K1, the second set of contacts can be used to stop the transport of a video tape recorder during commercial messages.

The transmitter can be housed in a standard plastic enclosure or, for dramatic fun, a plastic six-shooter such as that used by the author. The "gun," manufactured by Coleco for use in a game, contains a trigger-actuated switch and a lens system. The pc board pattern of Fig. 3B was designed for use with this gun. Careful attention to dimensions will ensure proper alignment of the LED with the lenses, giving a narrow, correctly aimed beam.

To fit a nine-volt battery into the handle of the pistol, the internal plastic posts between the holes for the two handle screws must be cut away. This can be done with a heated knife or with a hobby power tool and its saw blade. Also, the terminals on the rear of the trigger-actuated switch must be cut off. The necessary electrical connections between the switch and the rest of the transmitter circuit should be made by soldering suitable lengths of hookup wire directly to the switch's leaf springs. Use a vise to hold the switch and then tin the leaf springs and the ends of the lengths of hookup wire. Place the tinned end of each wire next to the appropriate leaf spring and remelt the solder to form the connection. Work quickly to avoid losing the temper of the springs. Finally, make a 1/8-inch hole in the plastic body over the position occupied by trimmer potentiometer R2 so that the circuit's frequency of oscillation can be conveniently adjusted.

If you prefer a more conventional transmitter enclosure, you will need a lens to focus the infrared beam. Focusing the invisible beam is difficult. Alter-
natively, you can use a Texas Instruments TIL31 or General Electric LED55C infrared-emitting diode. These include internal reflectors and glass lenses and mount in standard 0.200-inch LED mounting collars. They also tolerate larger forward currents, allowing reduction of the value of R4 in the transmitter to 15 ohms. Pass transistor Q1 and base resistor R5 in the circuit of Fig. 1A allow switch S1 to be a light-action, low-current keyboard switch.

Adjustment. After the receiver and transmitter have been assembled, plug T1 into a wall socket. With the top of the receiver enclosure removed, monitor the voltage across resistor R3 with a high-impedance multimeter. Place an unshaded, lighted 60-watt light bulb two feet away from the filter that shields phototransistor Q1, and set the wiper of trimmer potentiometer R2 fully counterclockwise; the voltage across R3 should be 2.5 ±0.5 V. If necessary, change the value of R3 to obtain this reading. Should this prove impossible, try another FPT-100 phototransistor.

When the voltage across R3 is correct, cover the filter aperture with a totally opaque shield and adjust R2 so that 0.25 volt appears across R3. Then remove the opaque shield.

Next, turn R16 fully counterclockwise and check the voltage at TP2. This should be 0 volt. Slowly turn R16 clockwise. At some point, TP2 should suddenly go to +5 volts. When this happens, back R16 off and stop just past the point at which TP2 returns to 0 volt. Depress switch S1 momentarily and verify that TP1 goes to +5 volts with S1 closed and returns to 0 volt when it is

Fig. 6. Parts placement guides for the box-style (A) and gun-style (B) infrared transmitters.

Fig. 7. Parts placement guide for the AD*ZAP infrared receiver printed circuit board.

Fig. 8. Component placement guide for the relay pc board.

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The latter case, the potentiometer of the CRT is controlled, and how the range of the brightness potentiometer is affected by the "one-button" color preset, if any.

Several methods of brightness control are common; the simplest is found in many vintage color receivers and in many contemporary monochrome models. (Figure 9 is typical.) The video signal is capacitatively coupled to the cathode of the picture tube, and the brightness potentiometer controls the dc bias voltage that sets the average beam current. The lower the bias voltage, the higher the beam current and the brighter the picture. Resistor R34 limits the beam current to a maximum value.

Brightness-control circuits of this type almost always are able to send the CRT well past cutoff (screen completely dark). If you have a color receiver that employs a similar circuit (the partial schematic illustrated is of a General Electric HB color chassis), note that the red, green, and blue screen controls interact with the brightness control. While a video signal is being received, try adjusting the screen controls for cutoff with the brightness control at its minimum setting. Then if the CRT image is too dim when the brightness control is advanced to its maximum setting (this will rarely be the case), make the value of R34 half as large. Check to see that the high voltage is at its specified value before making a substitution for R34.

The more usual approach to brightness control in today's solid-state receivers is to vary the dc bias at the input of one of the video amplifiers. Video is either dc or coupled (or a combination of the two) into the stage, and is sometimes clamped to the bias voltage during the blanking interval. The brightness potentiometer can be wired into the circuit either as a voltage divider (as a three-terminal device) or as a variable resistor (a two-terminal device). In the latter case, the potentiometer is only part of a voltage-dividing network. The Sharp Model XR-2194 typifies the first method, the Sony 9000U the second.

In the Sony, the bias voltage of the video amplifier is mixed with the video signal. The video signal is positive, that is, white is more positive than black. Blanking the screen can therefore be accomplished by bringing the base of the video stage to ground, either directly or by opening the path between the voltage divider that sets the bias and the low-voltage supply from which the bias is derived. In the Sharp receiver, the "one-button" color-preset switch selects between the brightness control and a screwdriver adjustable trimmer potentiometer that is preset at the factory. Both the front-panel brightness control and the trimmer have range-limiting series resistors that prevent them from cutting off the CRT totally. Blanking can be achieved by having the relay disconnect the ends of the front-panel and trimmer potentiometers that are tied together from the source of the low voltage which supplies them.

In some sets, the "one-button" color preset leaves the front-panel brightness control in the circuit, but restricts its effective range. One receiver that uses such a circuit is Toshiba's Model C345, chassis TAC-9310. The base of the fourth video amplifier is biased through a fixed resistor by a voltage divider composed of a fixed resistor and the brightness control, one end of which receives positive voltage via a sub-brightness control. This latter control limits CRT brightness.

When the receiver's "one-button" color preset is engaged, a fixed resistor is placed in parallel with the front-panel brightness control. This restricts the effective range of the control to its upper half. To have AD\*ZAP totally darken the screen, relay K2 can be wired either to ground the wiper of the SUB-BRIGHTNESS control or connect a fixed resistance of approximately 5000 ohms between the base of the fourth video amplifier and ground. The use of such a resistor rather than a direct short to ground prevents the total loss of the demodulated video signal, which would also disable the sync circuits. This way, when K2 is deenergized, the picture returns instantly—in sync and with no rolling or tearing. The relay pc board includes provisions for such a resistor (Rf) at point D*.

PARTS AND KIT AVAILABILITY

The following are available from Videomega, 2715 N.E. 14th Avenue, Portland, OR 97212. Prices do not include shipping and handling charges ($2 per order). Kits of all components for one transceiver, receiver, and relay board, enclosures, and a nine-volt battery for the transmitters: complete kit for AD\*ZAP system employing gun-style transmitter (limited quantities available), No. KZ-S, for $69.00; complete kit for AD\*ZAP system employing box-style transceiver, No. KZ-T, for $69.00; complete kit for AD\*ZAP system capable of controlling VTR pause circuit, employing gun-style transmitter, and including VTR control cable (limited quantities available), No. KZ-5, for $79.00; complete kit for AD\*ZAP system capable of controlling VTR pause circuit, employing box-style transmitter, and including VTR control cable, No. KZ-TV, for $79.00. Individual kits for additional receivers, transmitters, and relay boards are also available. Write for prices.

Dried, soldered, and silk-screened (component-placement legend) printed-circuit boards are also available separately: Set of boards for receiver, relay circuit, and gun-style transmitter, No. AZ-S, for $16.00; set of boards for receiver, relay circuit, and box-style transmitter, No. AZ-T, for $16.00; set of boards for receiver, relay circuit, and VTR pause-control circuits, and gun-style transmitter, No. AZ-SV for $16.00; set of boards for receiver, relay VTR pause-control circuits, and box-style transmitter No. AZ-TV, for $16.00; receiver board only, No. AZ-A for $7.50.

K1 should pull in and LED1 glow. When transmitter switch S1 is closed a second time, K2 and LED2 should do likewise. At the end of the interval determined by the setting of receiver switch S2, both relays should drop out and both LEDs darken. If S1 is closed a third time before the receiver times out, this too should de-energize the relays and LEDs. Closure of receiver switch S1 should initiate the timing sequence or, if it has already begun, interrupt it.

Modifying the TV Receiver. If control of only the audio output of the television is desired the AD\*ZAP system can be used with any TV set and installation procedure is simple. However, achieving control of both sound and picture may be somewhat more difficult, depending on the TV set used. Two simple tests will tell you how much of a problem it will be to obtain picture control. If the CRT screen goes completely black when the brightness control is at minimum, installation will be easy. Alternatively, if the receiver has a "one-button" color preset, and the screen goes completely dark when the preset is engaged and the brightness control is at minimum, installation is again not complicated. However, if the screen cannot be wholly "blackened," installation will be more
troublesome, as detailed in a boxed section on the opposite page.

Here's the procedure that should be followed if test results are positive. Begin by removing the rear panel of the TV receiver (which should also remove ac power through the interlock) to gain access to the BRIGHTNESS control. Detach the wire connected to the center lug of the BRIGHTNESS control and connect it to point D on the relay printed circuit board. The free ends of the wires from points E and F on the relay board should be soldered to the center and left lugs, respectively, as seen from the rear of the BRIGHTNESS control. To control the audio, disconnect one of the two output leads from the loudspeaker and connect it to point H on the relay circuit board. If necessary, extend the length of this lead by splicing on a piece of hookup wire. Solder the splice and insulate it using PVC electrical tape or heat-shrinkable tubing. Then attach one end of suitable length of hookup wire to the free speaker lug, and the other end to point G on the relay circuit board. The relay board can be mounted inside the television cabinet using either screws and standoffs or two or three layers of double-sided adhesive foam tape.

**Using AD'ZAP.** Although the receiver module includes an infrared filter, high levels of ambient light can affect phototransistor Q1. Therefore, avoid illuminating the sensor with bright sunlight, and keep incandescent lamps several feet away. The on-axis range of the six-shooter transmitter is more than 35 feet. That of the box-style transmitter is more than 20 feet. Because of its more diffuse radiation, the box-style transmitter need not be critically aimed.

Receiver switch S1 should be set to provide the desired delay interval. The growing use of 30-second commercial messages on television prompted the inclusion of the switch. A few hour's attentive viewing of TV programs and commercials will enable you to judge which delay interval is more useful. To be certain not to miss any desired program material, you may want to avoid darkening the picture, at least at first.
BUILD THE POOR MAN'S STROBE

Inexpensive circuitry allows timed, sequential flashes for multiple photographic exposures of moving subjects

BY IMRE GORGENYI*

STROBOSCOPIC photography, which exposes a single frame with light from a sequence of timed flashes, is an interesting way to capture a moving subject on film. The result is a series of still images that catch the subject in successive positions along its path, clearly suggesting motion. Stroboscopic photographs of a gymnast working out appear on the cover of this issue.

Unfortunately for shutterbugs, commercial equipment for stroboscopic photography is high in price. There are, however, circuits designed around readily available, inexpensive components that are easily built and will enable amateur photographers to experiment with the technique.

*Motorola Semiconductor Group

The Basic Poor Man's Strobe
The circuit (Fig. 1) triggers a flash unit at a predetermined time after the receipt of a light pulse from another flash unit actuated by the camera's flash-sync output. A portion of the light from the camera-triggered flash falls on the window of phototransistor Q1, which briefly conducts. The resulting negative voltage pulse at the collector of Q1 triggers the timing circuit comprising C1, R2 through R6, and Q2.

At the end of the timing interval, whose duration is adjustable by means of potentiometer R3, Q3 and its associated passive components generate a positive voltage pulse and couple it to the gate of SCR1. The SCR breaks into conduction and triggers the flash unit whose sync contacts are connected to jack J1. Simultaneously, the timing circuit resets itself by means of R6 to prepare for the next triggering light pulse. Power for the circuit is provided by a 9-volt alkaline battery via switch S1. Quiescent current drain is approximately 1 mA, so long battery life can be expected.

The delay between the arrival of the triggering light pulse and the actuation of the secondary flash can be varied from approximately 0.1 to 1 second. For shorter delays, the value of C1 can be reduced to 0.1 µF. If this is done and R3 is set for minimum resistance, the delay is so short that the attached flash unit can be used as a simple slave. Light from the slave will reinforce that from the camera-triggered unit and will yield brighter or more diffuse lighting of the subject.

Of course, a number of basic Poor Man's Strobes can be built and each one adjusted for a different delay time to produce multiple images on a single emulsion.

Other Circuits. The slave-trigger circuit in Fig. 2 has practically no delay at all. It is therefore suitable for situations in which the slight delay introduced by the timing circuit of the PMS would cause an undesirable second image or smearing. This circuit has two unusual characteristics—it is not triggered by steady-state ambient light, and it derives its modest operating power from the flash to which it is connected.

Although ambient light would tend to cause phototransistor Q1 to conduct, inductor L1 prevents this from happening. Upon receipt of a light pulse, however, a voltage is set up across the inductor and the base-emitter junction of the phototransistor, and the device briefly conducts. This in turn forward-biases the base-emitter junction of switching transistor Q2, and a positive voltage appears across R12. The SCR breaks into conduction and triggers the flash unit whose sync contacts are connected to jack J1. A manual trigger switch (S1) is wired in parallel with SCR1. Power for Q1 and Q2 is derived from the flash unit by means of voltage divider R3R4 and storage capacitor C1, which is wired in parallel with the R3 leg of the voltage divider. The circuit's power requirements are so modest that almost any flash unit can easily satisfy them.

The circuit shown in Fig. 3 is a sequential flash trigger that can ac-
tuate as many as five flash units. These units will be triggered at equal intervals after the camera's sync contacts close. The circuit functions as follows: when the sync contacts close, transistor Q3 cuts off and capacitor C2 begins to receive charging current from the constant-current source comprising Q4, Q5, and their associated passive components. The ramp voltage that appears across the capacitor is coupled to position 1 of switch S2 by Darlington emitter follower Q6. If S2 is in position 1, the ramp voltage is applied to the gates of SCR2, SCR3, SCR4, and SCR5 through a series of voltage dividers. The gate of SCR1 receives a separate voltage pulse via a different circuit path almost immediately after the camera's sync contacts close.

As the ramp voltage at the pole of S2 increases in amplitude, SCR2, SCR3, SCR4, and SCR5 successively break into conduction and trigger the flash units to whose sync contacts they are connected. The rate at which the SCRs fire is determined by the slope of the ramp, which is ultimately controlled by the setting of SPEED potentiometer R9. The lower the resistance of R9, the greater the output of the constant-current source. Thus, more current will flow through LED1, and the LED will glow more brightly to indicate that the slope of the ramp will be steep and the flash sequence rapid. The total duration of the flash sequence can be adjusted from approximately 50 milliseconds to 3 seconds.

The monostable multivibrator comprising Q1, Q2 and associated passive components performs two functions. First, it triggers SCR1 when the camera's sync contacts close. Then, after three seconds, it resets the rest of the circuit to prepare for the next flash sequence. When switch S2 is in position 2, the initial pulse across R1 is simultaneously applied to the gates of SCR1 through SCR5, triggering all the flash units simultaneously. Power

**PARTS LIST**

<table>
<thead>
<tr>
<th>Part</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>9-volt alkaline battery</td>
</tr>
<tr>
<td>C1</td>
<td>10-µF, 16-V tantalum capacitor</td>
</tr>
<tr>
<td>C2</td>
<td>0.001-µF, 50-V disc ceramic capacitor</td>
</tr>
<tr>
<td>J1</td>
<td>Suitable jack (chosen to match the plug of the flash unit's sync extension cord)</td>
</tr>
<tr>
<td>Q1</td>
<td>2N5780H npn silicon phototransistor</td>
</tr>
<tr>
<td>Q2</td>
<td>MPSA70 pnp silicon transistor</td>
</tr>
<tr>
<td>Q3</td>
<td>MPSA20 pnp silicon transistor</td>
</tr>
<tr>
<td>Q4</td>
<td>MPSA20 pnp silicon transistor</td>
</tr>
<tr>
<td>Q5</td>
<td>MPSA20 pnp silicon transistor</td>
</tr>
<tr>
<td>R1</td>
<td>12-kΩ, 1/4-W, 10% resistor</td>
</tr>
<tr>
<td>R2</td>
<td>4.7-kΩ, 1/4-W, 10% resistor</td>
</tr>
<tr>
<td>R3</td>
<td>50-kΩ, 1/4-W, 10% resistor</td>
</tr>
<tr>
<td>R4</td>
<td>470-kΩ, 1/4-W, 10% resistor</td>
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<td>330-kΩ, 1/4-W, 10% resistor</td>
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<td>10-kΩ, 1/4-W, 10% resistor</td>
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<tr>
<td>R7</td>
<td>10-kΩ, 1/4-W, 10% resistor</td>
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<td>R12</td>
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<td>R13</td>
<td>10-MΩ, 1/4-W, 10% resistor</td>
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<tr>
<td>R14</td>
<td>10-MΩ, 1/4-W, 10% resistor</td>
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<tr>
<td>C1</td>
<td>0.01-µF tantalum capacitor</td>
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<tr>
<td>C2</td>
<td>0.001-µF capacitor</td>
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<tr>
<td>C3</td>
<td>0.001-µF capacitor</td>
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<tr>
<td>C4</td>
<td>0.001-µF tantalum capacitor</td>
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<tr>
<td>C5</td>
<td>0.001-µF tantalum capacitor</td>
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<td>C6</td>
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<td>C7</td>
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<td>C8</td>
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<td>C15</td>
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<td>C16</td>
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<td>C18</td>
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<td>C19</td>
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<td>C30</td>
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<td>C31</td>
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<td>C32</td>
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<td>C33</td>
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<td>C34</td>
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<td>C36</td>
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<td>C37</td>
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<td>C38</td>
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<td>C47</td>
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<tr>
<td>C48</td>
<td>0.001-µF tantalum capacitor</td>
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<tr>
<td>C49</td>
<td>0.001-µF tantalum capacitor</td>
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</tbody>
</table>
The following, unless otherwise specified, are 1/4-W, 10% tolerance, carbon-composition fixed resistors:

- R1, R5 = 6.2 kΩ
- R2 = 100 kΩ
- R3 = 120 kΩ
- R4 = 8.2 kΩ
- R6, R17 = 22 kΩ
- R7 = 51 kΩ
- R8, R10 = 100 Ω, 1/2-watt
- R9 = 1 kΩ, linear-taper potentiometer
- R11, R12 = 27 kΩ
- R13 = 6.8 kΩ

For the circuit, the 9-volt alkaline battery B1 is supplied via switch S1.

Another sequential flash trigger circuit is shown schematically in Fig. 4. Here, the trigger pulse from the camera's sync contacts enables unijunction transistor Q1 to generate clock pulses that drive CMOS decade counter/decoder IC1. The rate at which clock pulses are generated is determined by the position of rotary switch S3, which selects one of five RC timing networks (R22C3 through R26C7). The gate of SCR1 is driven by the output pulses of the UJT, but the gates of the other SCRs are driven by various of the counter's decoded output lines. Switch S1 allows the user to determine whether the gate of SCR5 will be driven by the Q3 or Q5 output line of the counter—that is, whether the flash unit connected to...
Construction. The prototype Poor Man’s Strobes were assembled using perforated board and point-to-point wiring. However, printed-circuit construction can also be used. Type 2N5064 silicon controlled rectifiers are specified for each of the circuits that have been described. These devices have TO-92 plastic packages and are rated at 200 volts peak blocking voltage, 200 µA gate trigger current, and 6 amperes peak forward surge current. They are compatible with most flash units on the market. However, if you intend to use a flash unit that impresses more than 150 volts or so across its sync terminals, an SCR with a greater peak blocking voltage rating will have to be used.

Circuit layout is not critical, and the projects can be housed in any convenient enclosures. The various input and output jacks should be selected to match the plugs of the sync extension...
records that your photographic gear employs. Photographs of the prototypes whose circuits are shown in Figs. 1 and 3 appear with the respective diagrams. In the circuits of Figs. 1, 3 and 4, the use of alkaline cells will extend battery life. Be sure to observe standard CMOS handling procedures for IC1 of Fig. 4 and to use an IC socket to mount it.

**Using the Poor Man’s Strobes.**

As with any photographic hardware, a good deal of experimentation is required to learn how to use the Poor Man’s Strobes for the best results.

Start with two flash units in an unlit room with dark walls or wall coverings. If you are using the circuit shown in Fig. 1, connect one flash to the camera’s sync contacts and the other to jack J1. If you are using one of the circuits shown in Figs. 3 and 4, connect one flash unit to J2 and the other to J3. Run a sync extension cord from the camera to input jack J1. Place your camera in its “B” (bulb) exposure mode and either set the object to be photographed in motion or direct your model to move around the room. Trip the shutter and hold it open. One flash will fire immediately, and the other will be triggered after a delay. Release the shutter after the second flash has fired.

This first trial should be a “dry run” with no film in the camera. Your eyes will register the stroboscopic images. Repeat the experiment several times, varying the delay between the triggering of the two flash units and the rate at which the object or model is moving. If you have built several of the basic Poor Man's Strobes or one of the sequential trigger circuits shown in Figs. 3 and 4, add more flash units to see how multiple flash strobes will look.

Next, determine a sequence of connecting the flash units to the output jacks and applying power that does not result in inadvertent triggering of the units. The proper procedure might be as follows: apply power to the Poor Man’s Strobe; connect the flash units to it; and finally apply power to the flash unit.

Once you have acquired a feel for the Poor Man’s Strobe, you can take real pictures. Here again experimentation is needed. Vary the positions of the flash units, use different levels of light output, and for color work place different color filters on each flash unit. With a bit of experience, you’ll be able to turn out interesting and unusual photographs that are as much fun to display as they are to take.

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**COMMERCIAL KILLER FOR A CLOCK RADIO**

Low-cost system cuts off the audio on cue from the listener and restores it after one minute

**BY HERBERT L. BRESNICK**

Did you ever wish you could eliminate radio commercials and TV commercial sound? My clock radio, tuned to the local news station, is set for 6:00 a.m. This means 5 minutes of news interspersed with 5 minutes of commercials, and I find few things worse than listening to soap or laxative jingles at that hour! Fortunately, most commercials are exactly one minute long—which makes them not too hard to silence.

Basically, the system cuts off the audio on cue from the listener and uses a one-minute delay circuit to restore it—presumably after the commercial is over. Figure 1 shows the schematic diagram of the system, which uses about $3.00 worth of parts, depending upon the size and condition of your parts junkbox.

Here's how it works: As soon as the commercial starts, push switch S1 momentarily. This triggers IC1; a 555 IC timer chip, wired as a monostable. Triggering forces pin 3 of the IC high, operating relay K1, which pulls in, opening its normally closed contacts. These contacts, in series with the loudspeaker, squelch the audio. After one minute (as set by C1 and R1), pin 3 goes low releasing the relay and restoring the audio—just in time for resumption of the broadcast.

The circuit is easily wired, point-to-point on a 2" x 2" piece of perf board. Supply voltage (9 to 12 volts) is tapped from the radio or TV at any convenient point, and one speaker lead is placed in series with the relay contacts. It is recommended that a resistor be placed across the two leads that normally feed the speaker, as most power circuits do not like to be left unloaded. A 10- or 20-ohm resistor will do fine. Wrap the board with tape to protect the wiring and position it in a convenient space inside the receiver. The trigger wires can be brought out through the rear of the set, and connected to a pushbutton switch that can be placed at any convenient location.

Adding the "commercial killer" to my radio, has restored my sanity, and I'm able to face the morning shower, my wife, and the world with a smile. It may do as well for you.

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**PARTS LIST**

- C1—30-µF, 15-V capacitor
- C2—0.01 µF, disc capacitor
- IC1—555 timer
- K1—9-to-12-V, reed relay
- R1—1-MΩ trimpot
- R2—680 Ω, ½-W resistor
- R3—10-to-20 Ω, ½-W resistor
- S1—Momentary-contact pushbutton switch
- Misc.—Perf board, wire, solder, etc.

Fig. 1. Duration of silencer period is set by R1 and C1.

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EXPERIMENTER'S HANDBOOK
Cancel Rumble With This Bass-Summing Amplifier

Versatile project can also be used as an electronic crossover for a subwoofer power amp.

By John H. Davis

The presence of deep bass in the output of an audio system adds a satisfying "floor" to reproduced program material. However, designing a system to reproduce low frequencies well heightens the probability that rumble will make itself disconcertingly apparent. Presented here is the Bass Summing Amplifier, a project that can attenuate rumble without adversely affecting the low-frequency content or the high-frequency separation of a phonograph disc. It can also be used as an electronic crossover that sums the extreme bass to feed a subwoofer power amplifier. The Amplifier is easily and inexpensively constructed and requires no critical components or adjustments.

Rumble is low-frequency noise that is generated by phonograph recording and playback equipment. High-pass filtering can attenuate subsonic noise to a large extent, but it can't suppress audible rumble without also removing some desired bass content.

Most of the rumble entering a phonograph cartridge does so as vertical modulation that results in out-of-phase electrical signals at the phono cartridge's outputs. If these low-frequency out-of-phase signals are combined, they will cancel each other. Since recordings contain little or no out-of-phase, low-frequency information, low-frequency summation does not appreciably degrade the program material. What little bass separation exists and is recorded is not audibly significant to human beings. Psycho-acoustic studies indicate that bass localization is mostly a function of attack transients and overtones.

To verify that bass summing will attenuate rumble, play a silent groove on a vinyl disc and increase the volume until the rumble can readily be heard. Then switch your amplifier or preamplifier to its monaural mode. If your left and right channels are balanced and in proper phase, you will hear a drop in the rumble level.

About the Circuit. A schematic of the Bass Summing Amplifier appears in Fig. 1. Line-level stereo inputs are applied to jacks J1 and J2. Unity-gain inverters IC1A and IC1D shift the phase of the input signals by 180°. However, the unity-gain, low-pass filters comprising IC1B, IC1C and their associated passive devices do not appreciably alter the phase of those components of the input signals below their cutoff frequencies. If the outputs of IC1A and IC1B and those of IC1C and IC1D are combined, the low frequencies will cancel, leaving inverted midrange-and-treble stereo signals.

If the bass outputs of IC1B and IC1C are combined, a composite, summed bass signal results. This summed bass contains all of the in-phase information but no difference information. If this composite bass is recombined with the middle-and-high-frequency stereo signals, the result is almost indistinguishable from the original—except for the lack of rumble components. Because the operation of IC1A and IC1D involves phase inversion, IC2B and IC2D perform an additional compensating inversion.

The performance of the project in the rumble-suppressing mode is summarized by the graphs of Fig. 2. The heavy curve shows the extent to which low-frequency difference information is cancelled when the low-pass filters have cutoff frequencies of 220 Hz. The lighter-weight curve shows the extent to which channel separation is maintained as a function of frequency. Two dashed curves show the measured separation available from modestly priced and premium phono cartridges. These latter curves demonstrate that, above bass frequencies, the project does not adversely affect realizable separation.

A monaural signal that can be used to drive a subwoofer power amplifier is available at the output of IC2C. This filtered and summed bass signal is in phase with respect to the bass components of the stereo input signals. However, in this application, resistors R17 and R19 must be deleted so that the summed bass is not also present in the stereo outputs. Accordingly, the stereo system handles only the upper bass, midrange, and high frequencies. Figure 3 shows the low-pass-filter response that characterizes the output presented at J4 for a cutoff frequency of 110 Hz. The stereo out-
bass-summing amplifier

Components denoted by an asterisk can be deleted if the optional, dynamic separation indicator is not to be built.

C1,C2,C3,C4—Metalized polyester, metalized Mylar, monolithic ceramic or polystyrene capacitor, 10% or closer tolerance (see Table I for capacitance)

C5,C7—10-µF, 50-V, axial-lead, nonpolarized electrolytic

C6—25-µF, 50-V, axial-lead, nonpolarized electrolytic

C8,C9,C20—1000-µF, 25-V, radial-lead electrolytic

C10,C11—1000-µF, 25-V, axial-lead electrolytic

C12,C13—0.1-µF, 50-V disc ceramic capacitor

C14*,C15*—0.033-µF, 100-V Mylar capacitor

C16*,C17*—0.33-µF, 35-V tantalum capacitor

C18*,C19*—0.68-µF, 35-V tantalum capacitor

C21*—0.15-µF, 100-V Mylar capacitor

C22*—0.001-µF, 100-V Mylar capacitor

D1*,D2*,D3*—IN300 silicon switching diode

D4*—IN4001 rectifier

F1—¼-ampere fast-blow fuse

IC1,IC2,IC3*—TL074CN quad B/FET operational amplifier

IC4*—LM324N quad operational amplifier

J1 through J5—RCA phono jack

LED1*—Red light-emitting diode

LED2*,LED3*—Green light-emitting diode

The following, unless otherwise specified, are 1/4-watt, 5% tolerance, carbon-film fixed resistors.

R1,R2—15 kΩ

R3 through R27, R30* through R35*, R41*, R42*—100 kΩ (see text for recommended preselection procedure)

R28,R29—68 Ω, 1/2-watt

R36*,R37*,R44*—22 Ω, 1/2-watt

R38*—330 kΩ

R39—120 kΩ

R40*—82 kΩ

R43*—27 kΩ

R45*,R46*,R47*—880 Ω

RECT1—1-A, 100-PIV modular bridge rectifier

S1—Dpdt switch

S2—Spst switch

T1—24-V, 300-mA, center-tapped step-down transformer

Misc.—Printed-circuit board, standoffs, suitable enclosure, fuseholder, line cord, shielded cable, hookup wire, suitable hardware, strain relief, solder, etc.

Note: A partial kit of parts, No. BPKA, including etched and drilled printed-circuit board, matched C1 through C4 capacitors, and set of preselected R3 through R22 resistors, is available for $13.95 postpaid in U.S. (Georgia residents, please add state and local sales tax.) from Roland Electronics, P.O. Box 516, Greenville, GA 30222.

PARTS LIST

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ence information. The output of IC3A is rectified by IC3B and D1, and charges C18.

Summed bass is available at the output of IC2C (point C in Fig. 1). It is brought up to an equivalent level by amplifier IC3C. The frequency response of this stage is shaped by capacitors C21 and C22 to attenuate the unwanted higher frequencies. The amplified, summed bass output of IC3C is rectified by IC3D and D2, and charges C19.

Comparators IC4A, IC4B, and IC4C compare the two resulting dc levels and light LED3, LED2, and LED1 at progressively higher levels of separation. The network comprising D3, D4, R43 and R44 maintains a small bias voltage across C19. This prevents random triggering of the comparators by noise at low signal levels. Such triggering would otherwise be troublesome because signal comparison is based on ratios, not fixed voltage levels.

Options and Modifications. Before undertaking construction, you should determine exactly what function(s) you want this project to perform. If you want only to suppress rumble, you will probably want a filter cutoff frequency of 220 Hz (330 Hz if the rumble is severe). Table I shows which values of capacitors and resistors to use for these frequencies. Also listed are component values for a cutoff frequency of 110 Hz, which is a better choice if a subwoofer is used.

In a Bass Summing Amplifier to be used for rumble reduction only, there are a few components which can be eliminated (C6, J4, and R26). To drive a subwoofer power amplifier in addition, however, two resistors (R17 and R19) must be deleted. Whether the project is used for both purposes or only for rumble suppression, you have the option of including the separation indicator. If you choose not to include it, some parts can be deleted. They are denoted by an asterisk in the Parts List.

Construction. There are no high-gain or other stages in which circuit layout is critical. However, the use of a printed-circuit board is recommended because of the rather high parts count. The full-size etching and drilling guide for a suitable pcb board appears in Fig. 5. Its corresponding component placement guide appears in Fig. 6. The use of IC sockets or Molex Soldercons is recommended.

There are a few points to consider concerning component selection. To minimize distortion, the capacitors in the low-pass filters (C1 through C4) should be metallized plastic-film or other high-quality components. For the same reason, C5, C6, and C7 should be nonpolarized electrolytics. Purists will also want to connect 0.1-µF metallized plastic-film capacitors in parallel with C5, C6, and C7.

Carbon-film, 5%-tolerance resistors are acceptable for use in this project, but a simple preselection procedure requiring only an ohmmeter is recommended. The ohmmeter need not be particularly accurate, but should allow you to resolve slight differences in resistance around a center value of 100 kilohms. Exact values are not as important as close matches.

First, measure the values of some 100-kilohm resistors and set aside four that match very closely for R15.

### Table I

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Recommended Application</th>
<th>R5, R6, R7, R8 (100 kΩ)</th>
<th>C1, C3</th>
<th>C2, C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>110 Hz</td>
<td>Rumble suppression and subwoofer crossover</td>
<td>0.02 µF</td>
<td>0.01 µF</td>
<td></td>
</tr>
<tr>
<td>220 Hz</td>
<td>Rumble suppression</td>
<td>100 kΩ</td>
<td>0.01 µF</td>
<td>0.005 µF</td>
</tr>
<tr>
<td>330 Hz</td>
<td>Suppression of severe rumble</td>
<td>68 kΩ</td>
<td>0.01 µF</td>
<td>0.005 µF</td>
</tr>
</tbody>
</table>

1984 EDITION
Testing. Doublecheck the circuit assembly. Then apply power and verify that the positive and negative supply voltages are equal and less than 18 volts. A one-volt, 30-Hz signal applied to J1, the left input jack, should result in the appearance of half-volt signals at both J3 and J5, the left and right output jacks. If the project has been built for subwoofer use, the half-volt signal should appear at J4, the subwoofer output jack, only. If a 30-Hz, one-volt signal is applied to J1 and J2 simultaneously, the outputs at J3 and J5 or the output at J4 should increase to one volt.

If you have built the dynamic separation indicator, you can test its operation by applying a 30-Hz signal. When the input signal is applied to either J1 or J2 (but not both), all three LEDs should glow. Ideally, they should all extinguish when both channels are driven by the same input signal. Check to see if this happens.

Next, change the frequency of the test signal to 3000 Hz but keep its amplitude at one volt. Apply this signal to J1. A one-volt signal should now appear only at J3. Then apply the signal to J2 and verify that an output appears only at J5. At this frequency, none of the LEDs should glow, even if only one channel is driven. If LED3 does glow, decrease the level of the input signal to see if it extinguishes. (These statements assume, of course, that S1 is open.)

If you don't have access to test equipment, you can patch the project into your system at a line-level point in the signal chain. The Bass Summing Amplifier should be connected after any signal-processing components such as an equalizer, a dynamic-range expander, etc. Then find a quiet groove on a vinyl disc and play it. Listen for rumble, and open and close switch S1. A difference in the rumble level should be noticeable. During such a test, LED3 might flicker, but the other two LEDs should flash only very rarely.

Use. For the Bass Summing Amplifier to function properly, your audio system needs to be well balanced at the point at which signals are routed to the inputs of the Bass Summing Amplifier. Use the monaurally recorded bands of a test record, or listen to a quiet groove of a standard disc.

### AUTHOR'S SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tr>
<td>Input Impedance</td>
<td>10 kΩ</td>
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<tr>
<td>Recommended Load Impedance</td>
<td>10 kΩ or greater</td>
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<tr>
<td>Total Distortion</td>
<td>Less than 0.05%</td>
</tr>
<tr>
<td>S/N</td>
<td>Better than 70 dB (unweighted)</td>
</tr>
<tr>
<td>Frequency Response</td>
<td>50 Hz to 16 kHz + 1 dB at stereo outputs</td>
</tr>
</tbody>
</table>

Fig. 4. Schematic diagram of the Dynamic Separation Indicator. The LEDs will light at progressively higher levels of separation.
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while adjusting interchannel balance. Maximum cancellation occurs when the channels are exactly balanced. Even high-quality phono cartridges have some imbalance, and as much as 2 dB will degrade the rumble-cancelling capability of the project.

The net result of your efforts will be quieter and more satisfying bass. As a bonus, the bass summing amplifier can be used to reduce rumble on tapes that have been dubbed from noisy turntables or from FM broadcasts generated using outdated studio equipment.
How to check out and use modules that clutter your junk box

AC ADAPTERS for operating portable equipment such as radios, tape decks, calculators, or shavers from the power line instead of the usual batteries represent an often unrecognized resource for the electronics experimenter. The chassis for a project can often be made smaller and cheaper if one of these devices is used to supply operating power. And if small children are involved in any way with the project, the isolation from the power line provided by the adapter can be a safety factor. In addition, one adapter can power several projects if they are not all in use at once. Best of all, you probably have several of these devices left over from old, discarded appliances.

Types of Units. Since adapters are designed to reduce the nominal 117 volts at the wall socket to a lower voltage, all of them contain a small low-power transformer. There are two basic outputs from these devices; ac only or some form of dc. To identify the output, read the label on the case. If the label cannot be read, an oscilloscope across the output with a light resistive load (1 to 5 kΩ) will quickly identify it. An ac-only device will display a line-frequency sine wave, while a dc-output device that incorporates filtering will show a dc level with a small amount of ripple. If there is just a rectifier with no filtering, a line-frequency half sine indicates half-wave rectification while a series of half sines at twice the line frequency indicates full-wave rectification.

Testing. The setup used for testing ac and dc output adapters is shown in Fig. 1. The only practical difference between the two types is that a rectifier is used with the ac device.

With the load resistor disconnected, the supply will deliver its maximum dc voltage (1.41 times the rms value of the transformer output voltage) Construct a graph with voltage on the vertical axis and current on the horizontal axis. The upper end of the voltage axis is marked with the maximum (unloaded) voltage from the test circuit; from that point to the bottom (where this line joins the current axis) divide the voltage axis evenly into volts and parts of volts.

Ohm's Law (R=E/I) is used to determine the value of load resistor used. If, for example, the dc output is 15 volts, a 15,000-ohm resistor will draw 1 mA, a 1500-ohm resistor 10 mA, and a 150-ohm resistor 100 mA. If we wanted to start the current plot at, say, slightly under 10 mA, then a potentiometer (5-watt) having a value of 2000 to 2500 ohms will be required. To avoid burning out the module when the pot is set upward to its low end, connect a 150-ohm, 2-watt resistor in series with the potentiometer to limit current flow to 100 mA. This latter resistor can be reduced if the supply proves capable of delivering more than 100 mA.

Adjust the potentiometer until the current meter indicates 10 mA. Observing both meters, plot the voltage and current on the graph. Reduce the potentiometer resistance until 15 mA is flowing. Plot the voltage and current again. Repeat these steps until you have sufficient data to construct a curve like that in Fig. 2. During these tests, make sure that the transformer does not overheat (though it may feel warm to the touch), indicating excessive current drain.

An oscilloscope connected across the output of a dc supply may show considerable ripple, particularly if the supply uses a half-wave rectifier or is heavily loaded. To reduce this ripple, add more filter capacitance. As a general rule of thumb, doubling the capacitance will halve the ripple.

The graph you have drawn will give a close estimate of output voltage at any given load current. In addition, it allows you to determine regulation (the degree to which the voltage varies with load). This is expressed as the percentage of the open-circuit voltage measured with maximum output current. Thus, the curve shown in Fig. 2 indicates regulation of 48%. The higher the regulation, the better the supply.

Before an adapter is used to power a project, it should be tested under load for an hour or more. If the exterior case gets too hot to touch comfortably, a hazard may exist, and a higher capacity adapter should be used.
**ac adapters**

**AC Circuits.** Four typical rectifier circuits for use with ac-only adapters are shown in Fig. 3. A full-wave rectifier like that in Fig. 3A can be had as an encapsulated module or synthesized from discrete silicon diodes. A filter capacitor is added to smooth the output and produce useful dc. For low-current applications where cost is a big factor, a half-wave rectifier circuit can be used. This is shown in Fig. 3B. The voltage doubler (Fig. 3C) and tripler (Fig. 3D) will deliver two and three times, respectively, the open-circuit voltage of a half-wave supply but with only small currents. In addition, they have very poor voltage regulation and excessive ripple unless very large valued filter capacitors are used.

**DC Circuits.** These types of adapters usually have some internal filtering, but for good results require about 1000-µF of external filtering. To improve voltage stability under load, an external regulator module can be added. The most convenient type of regulator to use is a three-terminal regulator at (A) delivers a fixed voltage while the circuit shown in (B) is adjustable and regulated.

---

*Fig. 1. The difference between the test circuit for an ac and dc adapter is the rectifier required by the ac version.*

*Fig. 2. A typical load regulation curve used to evaluate an ac adapter.*

*Fig. 3. Four circuits for an ac adapter. Full-wave rectifier (A), half-wave (B), half-wave voltage doubler (C), and voltage tripler (D).*

*Fig. 4. Three-terminal regulator at (A) delivers a fixed voltage while the circuit shown in (B) is adjustable and regulated.*
three-terminal device such as the 7805, 7809, or 7812. These accept up to 35 volts input and deliver 5, 9, and 12 volts respectively. A typical circuit is shown in Fig. 4A. This circuit is ideal for non-critical, low-power applications, and is inexpensive. Three-terminal regulators are very rugged, and have internal circuits to protect them from overheating and overload. Keep in mind that the input voltage to the regulator must be at least 2.5 volts higher than the desired output voltage with maximum current drawn from the supply.

The graph of Fig. 5 illustrates a dc source applied to a 9-volt regulator with the ripple voltage added. Note that as the output current increases, the output voltage comes closer to the desired regulated voltage. At some current, the regulator input voltage will intersect the lower edge of the ripple band. This then becomes the maximum allowable output current for this particular combination. This curve illustrates the need for load testing a finished supply.

By using a "third generation" three-terminal regulator such as that shown in Fig. 4B, a variable regulated voltage from about 1.2 volts to the input voltage minus 2.5 volts can be built.  

**Multi Voltages.** Circuits requiring more than one dc voltage are shown in Fig. 6. For a dc adapter, the simplest approach is Fig. 6A. This circuit delivers 12 and 5 volts, both regulated. An ac adapter can use the circuit shown in Fig. 6B to deliver both a positive and negative voltage. If desired, a 7905 can be used in the negative line to deliver regulated −5 V, while a 7805 in the positive line delivers regulated +5 V. The circuit in Fig. 6C can deliver both positive and negative voltages if the output of the dc adapter is about two V higher than the sum of the two output voltages. The LM317 is set to the sum of the two voltages, while the 741 op amp forces the two transistors to sink current from both loads. This creates a common line that is treated as the circuit ground. This circuit can be used to create positive and negative voltages of equal or unequal magnitude, depending on the ratio of R1 to R2. Both voltages will be as well regulated as the output from the regulator.

A negative voltage may be generated from a positive supply by a circuit called a "charge pump" as shown in Fig. 6D. This circuit uses alternate cycles of the transformer voltage to charge C2 via D1. The other half cycle, selected by D2, turns on Q1. When Q1 is turned on, the charge on C2 is dumped via D3 into C3, creating a negative voltage. With the values shown, this circuit has about 30% regulation.

A perusal of the many books covering power supplies will show a number of other circuits that can be adapted for use with ac and dc output power line adapters. With this information, it is possible to salvage most of those previously useless ac and dc adapters.
AN ALARM FOR TOXIC GASES

Detects oxygen-hungry gases such as carbon monoxide and methane... sounds a warning before dangerous concentrations are reached

BY CASS LEWART

WHEN a lethal fire starts, flame and smoke are not the only killers. Colorless, odorless carbon monoxide gas (CO) has been known to kill or incapacitate people—often far from the fire itself. One factor that makes CO such a stealthy, insidious assassin is its ability to elude conventional smoke detectors. These devices are similarly insensitive to dangerous hydrocarbon gases like methane (CH₄), a toxic compound that is the chief component of natural gas.

The Gas Alarm described here has been designed to sound its warning before dangerous levels of poisonous gases accumulate. The Gas Alarm should be considered complementary to, and not a replacement for conventional smoke detectors, as it will not respond to ionized gases generated by fire unless the fire is smoldering in an enclosed area lacking oxygen. This project has the advantage of being self-powered, thus providing portable protection both at home and in hotels or motels when you travel.

The alarm is based on an inexpensive semiconductor sensor whose electrical resistance changes when its active surface is exposed to gases such as carbon monoxide, methane, butane, and alcohol vapors that have a strong affinity for oxygen. (These are known as reducing gases.) The sensor element is enclosed in a small capsule and protected by a stainless steel mesh, while a low-power heater activates the sensor element and purifies it after exposure to gas.

Circuit Operation. As shown in Fig. 1, transformer T₁, fullwave rectifier RECT₁, resistor R₂, and filter capacitor C₁ make up the line-powered power supply for 5-volt regulator I₁. Resistor R₁, in conjunction with rectifier D₁, maintains the charge on the rechargeable cells in B₁, while diode D₂ allows B₁ to power the circuit in stand-by mode when the line power is interrupted. Under these conditions, D₁ is reverse biased and battery power flows through forward biased diode D₂ to power the circuit. The regulated output from I₁ maintains a fixed heater voltage for gas sensor TGS₁ to provide uniform sensitivity. The combination of R₃ and LED₁ forms a power-on indicator.

When gas is present at TGS₁, the
resistance of its sensor element drops, raising the voltage applied across calibration potentiometer R4. The rotor of R4 is connected to the gate of SCR1, and when voltage at that point reaches approximately 0.3 V, SCR1 turns on, supplying power to alarm A1. The piezoelectric alarm specified for A1 interrupts current flow periodically, so SCR1 does not latch permanently on. Switch S1 allows for faster battery charging while the gas sensor is turned off.

Construction. The project will easily fit in a 6" x 4" x 2½" metal cabinet, and all components except the alarm and gas sensor can be mounted on perf board or multi-lug terminal strips using point-to-point wiring. Mount the socket for sensor on top of the cabinet for maximum exposure to surrounding air, and mount the alarm on the side or back of the cabinet for best audio output. The six rechargeable cells forming Bi can be mounted in readily available battery holders.

Adjustment. (1) Plug the Gas Alarm into a 120-volt ac outlet; (2) rotate CAL control R4 fully CCW for minimum resistance between the SCR gate and ground; (3) apply power and allow the sensor to stabilize for 1-2 minutes, then rotate the CAL control clockwise till the alarm sounds; (4) rotate CAL control CCW till the alarm stops. The alarm is now ready for operation. Test the system by Rubbing a drop of alcohol between your fingers, near the sensor. When the alarm sounds, repeat steps two through four.

The rechargeable batteries are trickle charged when the alarm is plugged into an AC outlet, and will be fully charged after approximately 24 hours. To ensure that the batteries are working properly, unplug the alarm and, after allowing it to stabilize with the batteries, repeat the alcohol test described above. The fully charged AA-size batteries should operate the sensor for over an hour during a power failure. For longer standby operation use C- or D-size rechargeables. These will operate the alarm longer, but also require longer charging time. When the alarm is not in use, open S1 to protect batteries from discharging through IC1.

Photo of the author's prototype.

Fig. 1. Schematic diagram of the circuit.

PARTS LIST

<table>
<thead>
<tr>
<th>Description</th>
<th>Part Number</th>
</tr>
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<tbody>
<tr>
<td>Al—Piezoelectric buzzer (Radio Shack 273-060 or similar)</td>
<td></td>
</tr>
<tr>
<td>Bi—Battery (six rechargeable 1.5-V cells)</td>
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<tr>
<td>CI—220µF, 16-V electrolytic</td>
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<tr>
<td>Di—D2—200-V, 1-A silicon diode</td>
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<tr>
<td>IC1—5-V regulator (Radio Shack 276-1770 or similar)</td>
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<tr>
<td>LED1—Red LED (optional)</td>
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<tr>
<td>R1—100Ω, 1/2-W resistor</td>
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</tr>
<tr>
<td>R2—15Ω, 1-W resistor</td>
<td></td>
</tr>
<tr>
<td>R3—270-Ω, 1/2-W resistor (optional)</td>
<td></td>
</tr>
<tr>
<td>R4—50-kf linear potentiometer</td>
<td></td>
</tr>
<tr>
<td>RECT1—50-V, 1-A full-wave rectifier</td>
<td></td>
</tr>
<tr>
<td>S1—Spst switch</td>
<td></td>
</tr>
<tr>
<td>SCR1—200-V, 6-A SCR (Radio Shack 276-1067 or similar)</td>
<td></td>
</tr>
<tr>
<td>TGS1—Gas sensor (See note)</td>
<td></td>
</tr>
<tr>
<td>T1—12-V, 1-A transformer (Radio Shack 273-1505 or similar)</td>
<td></td>
</tr>
<tr>
<td>Misc.—6&quot; x 4&quot; x 2½&quot; enclosure with cover, perf board or terminal strips, etc.</td>
<td></td>
</tr>
</tbody>
</table>

Note: The following is available from C&R Electronics, Box 217, Holmdel, NJ 07730: Pretested gas sensor, with socket, for $10.95 plus $1 postage and handling. NJ residents, add 6% tax. Allow 2 to 3 weeks for delivery.

1984 EDITION
SOME electronic components, especially semiconductors, are extremely sensitive to temperature changes. Even passive components (resistors and capacitors, for example), which are normally insensitive to temperature variations, can undergo parameter changes that are sometimes sufficient to influence circuit behavior.

Here is a quiz that will check your knowledge of how the parameters of some common electrical components (as well as a few rare ones) change with temperature. The quiz gives you the common name and electrical symbol or pictorial representation of the components and the parameters of interest under temperature change (resistance, voltage, etc.).

Your task is to answer the following questions about each component:

(A) Does the parameter of interest increase or decrease as the component’s temperature increases from 68°F (20°C) to 95°F (35°C)?

(B) Is the component frequently used in temperature measuring, control, or compensation circuits? As an example, for component No. 1, the thermistor, the answers are: (A) Decrease; (B) Yes. Answers for the rest are on the third page of the quiz. If you get 35 correct answers out of the total 50, you have done very well indeed.

<table>
<thead>
<tr>
<th>Component</th>
<th>Symbol</th>
<th>Parameter of interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Thermistor</td>
<td>![thermistor symbol]</td>
<td>Resistance</td>
</tr>
<tr>
<td>2 Silicon diode</td>
<td>![diode symbol]</td>
<td>Forward voltage drop</td>
</tr>
<tr>
<td>3 Silicon photovoltaic cell (Solar cell)</td>
<td>![solar cell symbol]</td>
<td>Power output</td>
</tr>
<tr>
<td>4 Copper wire</td>
<td>![copper wire symbol]</td>
<td>Resistance</td>
</tr>
<tr>
<td>5 Platinum wire</td>
<td>![platinum wire symbol]</td>
<td>Resistance</td>
</tr>
<tr>
<td>6 Electrolytic capacitor (A1)</td>
<td>![capacitor symbol]</td>
<td>Capacitance</td>
</tr>
<tr>
<td>7 Polystyrene capacitor</td>
<td>![polystyrene capacitor symbol]</td>
<td>Capacitance</td>
</tr>
<tr>
<td>8 NPO-type capacitor</td>
<td>![NPO capacitor symbol]</td>
<td>Capacitance</td>
</tr>
<tr>
<td>Component</td>
<td>Symbol</td>
<td>Parameter of interest</td>
</tr>
<tr>
<td>----------------------------</td>
<td>--------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>9 Class I ceramic capacitor</td>
<td></td>
<td>Capacitance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Carbon composition</td>
<td></td>
<td>Resistance</td>
</tr>
<tr>
<td>resistor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Positive temp.</td>
<td></td>
<td>Resistance</td>
</tr>
<tr>
<td>coef. silicon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>resistor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Insulated test lead</td>
<td></td>
<td>Insulation resistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 Thermistor (TC = -1000</td>
<td></td>
<td>Resistance between</td>
</tr>
<tr>
<td>ppm/°C)</td>
<td></td>
<td>points A and B (Assume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>perfect linearity)</td>
</tr>
<tr>
<td>14 NPN silicon transistor</td>
<td></td>
<td>DC Beta (current gain)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 Germanium diode</td>
<td></td>
<td>Reverse leakage current</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 Red LED</td>
<td></td>
<td>Radiant power (light</td>
</tr>
<tr>
<td></td>
<td></td>
<td>output)</td>
</tr>
<tr>
<td>17 Red LED</td>
<td></td>
<td>Wavelength of light</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Red = long wave</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Violet = short wave)</td>
</tr>
</tbody>
</table>

1984 EDITION
1. See introduction.

2. (A) Decrease; (B) Yes. Note: The silicon diode has a relatively linear forward voltage vs. temperature characteristic. It is also low-cost and readily available. However, it is comparatively insensitive.

3. (A) Decrease; (B) No. Note: Keeping the cell cool raises efficiency.

4. (A) Increase; (B) No. Note: Except possibly at high temperatures, copper's variation of resistance is seldom taken into account in designs.

5. (A) Increase; (B) Yes. Note: Platinum makes probably the best of the metallic type of temperature probe. Its advantages are: it can be highly refined; it resists contamination; it is electrically and chemically stable; its resistance characteristic is quite linear; and its drift and error with age are negligible.

6. (A) Increase; (B) No. Note: Seldom used in critical circuits.

7. (A) Slight decrease; (B) No. Note: The capacitance of polystyrene units varies little with temperature.

8. (A) Almost no change; (B) No. Note: NPO (Negative-Positive-Zero) is a temperature compensating dielectric that has an ultrastable temperature characteristic. Used in certain types of ceramic capacitors.

9. (A) Most decrease (B) Yes. Note: Some types of Class I ceramic capacitors, which are usually made of titanium dioxide, are frequently used in compensation circuits.

10. (A) Increase; (B) No. Note: This workhorse of the resistor world has quite a high temperature coefficient and thus isn't used frequently in critical circuits which must be temperature stable. Carbon-film, metal-film, or wire-wound resistors are better choices for application in critical circuits.

11. (A) Increase; (B) Yes. Note: Because of its fairly linear resistance/temperature characteristic (especially with a properly chosen fixed resistor in parallel) this component has possible use in simple digital thermometers.

12. (A) Decrease; (B) No. Note: Keep this in mind when testing high-voltage circuits.

13. (A) None; (B) No. Note: The thermistor resistance decreases by 0.1% for every degree Celsius increase in temperature (remember, 1000 ppm/°C = 0.1%) and the Sensistor resistance increases by an identical amount. Thus, the overall effect is zero.

14. (A) Increase; (B) Yes. Note: This effect has been used in inexpensive electronic thermometers. Also, it must be compensated for when designing a transistor circuit so that the transistor's operating point doesn't change significantly with temperature.

15. (A) Increase; (B) Yes. Note: A simple electronic thermometer can be constructed from a reverse-connected germanium diode, a battery, and a microammeter. The relatively high, temperature-dependent reverse leakage currents of germanium diodes make the silicon diode, whose leakage is far smaller, preferable in some applications.

16. (A) Decrease; (B) No. Note: Keep LEDs cool for increased brightness.

17. (A) Increase; (B) No.

18. (A) Decrease; (B) Yes. Note: Does this surprise you? Well, this is sort of a trick question. One normally thinks of a thermocouple's output as increasing with an increase in temperature. The fact is, a thermocouple's output increases with an increase in the difference in temperature between its standard junction and the test junction. Since the standard junction shown is at a constant 120°F, the thermocouple's output decreases until the test junction reaches 120°F, at which point the output is zero. For test junction temperatures above 120°F, the output increases with further increase in temperature. Since we are limited to a maximum temperature of 95°F, the output is said to decrease with increasing temperature.

19. (A) Increase; (B) No. Note: This answer is obvious to anyone who had no trouble starting his car on a relatively mild winter afternoon, but early the following morning, when it was bitter cold, had to jump the battery to start the car. (Of course, thickening oil exacerbates the problem.)

20. (A) Decrease; (B) No. Note: This effect is more important than most people realize. One answer is to store batteries in as cool an area as possible. A standard battery will retain nearly all its original capacity for as long as two years if stored at 32°F. This same battery, if stored at 160°F (say in an attic), will have only about 15% of its original capacity after only 1 month of storage!

21. (A) Increase; (B) No.

22. (A) Decrease; (B) No. Note: A substantial increase in temperature can trigger a false alarm. (Although the author has never seen it done, he speculates that a simple fire alarm can be constructed using an SCR with its gate clamped to a constant voltage just below the minimum trigger point (at room temperature).

23. (A) Almost none; (B) No. Note: This diode provides a reference voltage whose stability compares with that of standard cells.

24. (A) Decrease; (B) No. Note: Here is one reason why commercial-quality TTLs should be used only between 0° C and 70° C.

25. (A) Slight decrease; (B) No. Note: CMOS devices are less sensitive to temperature than TTLs. Plastic-cased CMOS are guaranteed to operate satisfactorily from -40°F to 185°F (-40° C to 85° C).

26. (A) Decrease; (B) No. Note: Spark gaps are frequently used to measure extremely high voltages. While this method may seem crude, it is accurate.
Low-cost digital indicator displays total playing time

HOW MANY HOURS ARE ON YOUR PHONO STYLUS?

Almost every hi-fi phono stylus is made from the hardest substance known to man—diamond. Even a diamond stylus, however, will become appreciably worn after a given number of hours of use. Keeping track of the number of playing hours a stylus has accumulated—and thus indirectly the degree to which it has become worn—is important for two reasons. Using a worn phono stylus dramatically reduces playback fidelity and can cause catastrophic, permanent physical damage to the grooves of a vinyl recording.

Presented here is a simple, inexpensive project that logs the number of hours a stylus has been used. This information is displayed at the push of a button on a four-digit, seven-segment LED readout to the nearest tenth of an hour. The low construction cost of this project—$50 or less—makes it an ideal solution to the problem of monitoring stylus use. With it, you will eliminate both the risk of using the same stylus too long and the needless expense of replacing it too soon.

About the Project. One principal design goal was to produce a circuit that would provide as accurate a count of actual stylus playing time as possible. This immediately ruled out the use of any scheme involving the sensing of the amount of time that the turntable was simply on. What was required was a method of determining the amount of time that the cartridge would actually be generating an audio output for subsequent processing by the phono preamp. This is the approach that was taken in the project described here.

The project is shown schematically in Fig. 1. Because there is no easy access to the output of the phono-preamp stage (apart from the fact that most equipment warranties would be voided by any such tampering), the stylus timer begins with its own RIAA phono preamplifier. The audio output of one of the cartridge's channels is tapped at the stereo system's phono-preamp input by means of a Y connector/adapter and a short patch cord. Sensing the input signal of only one audio channel was deemed suf-
Phono stylus

sufficient for the accuracy required. It is highly unlikely that long periods of time will exist in which there is a total absence of signal in one channel of a typical stereo disc.

The output of the phono cartridge is applied to Audio Input jack J1. One megohm of resistance (R1) and 20 pF or less of parasitic shunt capacitance comprise the input impedance of the project. This means that there is no additional, significant loading of the cartridge. Therefore, the stylus timer's input network does not appreciably alter the loading and hence sonic performance of the phono cartridge.

Operational amplifier IC1 boosts the level of the input signal and, with the help of R2, R3, C2 and C3, provides RIAA playback equalization. Because the op amp is powered by a single-ended supply, dc level-shifting of the input signal (performed by C5, R5 and R6) and capacitive input coupling (furnished by C1) are required. Output signals from IC1 are directly coupled to the non-inverting input of IC2D, which is one-fourth of an LM339 quad comparator. This stage is operated in linear fashion as an op amp with transistor Q1 inside the overall feedback loop. Resistors R10 and R11 determine the bias of Q1. Resistor R7 and capacitors C6, C7 and C9 furnish frequency compensation to ensure stability.

The 20 dB of gain provided by IC2D and the 40 dB of gain supplied by IC1 (at 1 kHz) boost the input signal to the level required by the half-wave rectifying and averaging network D4, C11 and R13. The amplified input signal is converted into a positive dc voltage appearing across capacitor C11, which charges rapidly and discharges slowly through R13.

Comparator IC2C accepts the dc voltage appearing across C11 and compares it with the reference of approximately 100 mV generated by R17, R18 and C12. Resistors R14 and R15 provide hysteresis to stabilize the comparator. The output of this comparator is applied to the noninverting input of comparator IC2B, while the inverting input receives a shaped timebase signal derived from the ac power line. Transformer T1 supplies a low-voltage 60-Hz sine wave to low-pass filter R19/C13, whose output is attenuated by voltage divider R20/R23. The attenuated sine wave, converted into a square wave with a dc offset by IC2A, is applied to the inverting input of comparator IC2B.

This comparator passes timebase pulses when audio from the cartridge drives the output of IC2C high. Timebase pulses then reach the clock input of the first section of dual D flip-flop IC3. The mismatch between pull-up re-

Parts List

B1—4.2-V mercury battery (Mallory No. TR-133 or equivalent)
C1—0.0033-µF Mylar capacitor
C2—0.0027-µF Mylar capacitor
C3—0.01-µF Mylar capacitor
C4, C8, C10—10-µF, 6.3-V tantalum capacitor
C5, C11, C12—100-µF, 10-V, radial-lead electrolytic capacitor
C6—0.1-µF disc capacitor
C7—0.001-µF Mylar capacitor
C9—0.005-µF disc capacitor
C13—0.01-µF disc capacitor
C14—100-µF, 35-V, radial-lead electrolytic capacitor
C15—330-µF, 6.3-V tantalum capacitor (see text)
C16—56-pF disc capacitor
D1, D2—1N4001 rectifier diode
D3, D4—1N914 signal diode
D4—1N34 germanium signal diode
D5—1N4736 6.2-V zener diode
D51—Four-digit, common-cathode LED display (NSA 1541 or equivalent)
IC1—LM301A operational amplifier
IC2—LM393 quad comparator
IC3—CD4013 dual D flip-flop
IC4—CD4059 programmable divide-by-n counter
IC5—MM744925 four-decade counter with multiplexed four-digit, seven segment output drivers
J1—Insulated phono jack
Q1 through Q5—2N5210 or equivalent npn silicon transistor
Q6—2N5086 or equivalent pnp silicon transistor
R4—470 ohms
R5—470 ohms
R6—1K1 ohms
R7—10 ohms
R8—120 ohms
R9—1K1 ohms
R10—15,000 ohms
R11—10,000 ohms
R12—100 ohms
R13—100 ohms
R14—100 ohms
R15—33,000 ohms
R20—33,000 ohms
R24, R25—R37—3900 ohms

www.americanradiohistory.com
Note: The following are available from TOLECO Systems, Box 401, Kingston, WA 98346: kit of parts consisting of all required integrated circuits, common-cathode LED display, and etched, drilled, and plated glass-epoxy printed circuit board, No. ST-1, for $34.95 plus $2.00 postage and handling in the U.S. and Canada, $4.00 all other countries; etched, drilled, and plated glass-epoxy printed circuit board, No. ST-2, for $10.00 postpaid in U.S. Washington residents, add 8% sales tax. No COD or foreign-currency orders. As designed, the project is suitable for use only in those areas where power-line frequency is 60 Hz.

R35—330-ohm, 1/4-watt resistor
S1, S2—Normally-open, momentary-contact pushbutton switch
T1—24-volt center-tapped, 40-mA step-down transformer
Misc.—Printed circuit board; IC sockets or Molex Soldercons; battery holder; fuse holder; suitable enclosure; Y phone-connector/adapter; shielded cable; phono plugs; hookup wire; line cord and strain relief; suitable hardware; solder; etc.

**Construction.** The high impedances and gains of the early stages of the signal-processing chain make the use of a carefully designed printed-circuit board almost a necessity. An etching and drilling guide and component layout are shown in Fig. 2. To keep construction cost low, a single-sided pc board using several jumper wires was used. As long as the jumpers are as short as possible and are installed neatly, they need not be insulated.
After the jumpers are in place, install the resistors, and then the diodes—in the correct polarity. Molex Soldercons or IC sockets should be mounted on the board after the diodes, and then the capacitors should be installed. (The polarities of electrolytic capacitors must be observed.) Finally, the transistors should be installed. Using a small-tipped, low-wattage soldering iron and a small-diameter (No. 22 AWG or similar), 60/40 rosin-core solder, make all necessary connections.

When all pc components have been mounted on the board, use suitable lengths of shielded cable and hook-up wire to connect the appropriate foil pads to those components that are not mounted on the board. Connect the shield of the cable running between input jack J1 and the input foil pads at both ends. However, use an insulated phono jack to prevent a ground loop from arising. A suitable length of multiconductor ribbon cable can be used between the pc board and the display.

The author's prototype is housed in an aluminum utility box that encloses everything except the LED display and the view switch. These were mounted on a small piece of oak and interconnected with the boxed section by a length of multiconductor ribbon cable. This arrangement permitted the placement of the utility box behind the audio preamplifier and the attachment of the oak display board to the rear of the turntable. The reset switch was mounted inside the enclosure to prevent accidental switch closure and loss of count.

The display used by the author is a four-digit calculator-type readout selected for small size and low current demands. However, almost any type of LED display can be used, so long as it is compatible with multiplexing. Discrete-digit LED readouts can be used in this application if all pins corresponding to the same display segment (a, b, c, etc.) are connected together to the appropriate outputs of IC5. Any available display color is acceptable. However, the use of a LED readout other than the one specified might require a change in value of current-limiting resistors R27 through R33. Increasing the resistances will result in diminished display current and brightness. Decreasing them will cause more current to flow and more light to be radiated by the display segments. The output drivers of IC5 can source a maximum of 30 mA, so the lower limit of resistance for R27 through R33 is approximately 100 ohms.

Transformer T1 as specified is a 24-volt center-tapped component with a rated secondary current of 40 mA. The author's prototype has an actual current
When working with very narrow, low-amplitude, low-energy pulses, it is advantageous to calibrate the scope you are using at actual working conditions with probes and attenuators in place. This is not always easy since pulse amplitude calibrators usually have low-level outputs—often under one volt.

The simple, all-FET circuit shown here provides pulse amplitudes to 25 volts, if desired, from pulse inputs of 5 to 20 volts. Since the two FET pairs are driven to their open-saturated condition, output pulses have the same amplitude as the power supply voltage. Absolute amplitude of the output can be monitored by a DVM at all times.

The circuit can handle narrow pulses and slow repetition rates. It can be assembled on a small piece of perforated board using BNC connectors for the input and output and can be connected directly in the 50-ohm line between the pulse generator and scope. The circuit, including power supply and digital voltmeter connectors, is "floating." Circuit protection is formed by the fuse and zener diode.

When the standby (S1 open) or view (S1 closed) mode. In the latter, the flow of display current causes a decrease in current flow through zener diode D5. This is why the overall current demand remains constant whether the readout is glowing or not. If a display requiring more current is used, T1 will have to be a component that can deliver more secondary current.

In any event, to minimize hum pickup and possible false time counts, the transformer should be positioned as far away from the input stage as possible. Its leads should be routed along the opposite side of the pc board from the input cable, or, even better, at the opposite side of the board and at right angles to the input cable.

**Installation and Use.** For initial checkout, plug the line cord into an ac power socket and depress the view pushbutton switch. The display should read 000.0. If it indicates some other number, momentarily close the reset switch and verify that the display returns to 000.0 when the view switch is closed again.

Next, position the project near your turntable and preamplifier in such a way that the LED display can easily be seen. Make sure that the audio system is turned off. Then disconnect one of the signal cables running from the turntable to the phono input jacks of the system's preamplifier. Either the right- or left-channel output of the turntable can be used. Connect a suitable J adapter to the unoccupied preamplifier phono input jack and plug the floating output cable from the turntable into one of the adapter's two phono jacks. Finally, connect one end of a patch cord to the remaining J adapter phono jack, and the other end of the patch cord to the project's audio input jack (J1).

Turn the stereo system on and play a record for slightly more than six minutes, verifying that the display reads 000.1 hour when the view switch is closed. If it does, return the tonearm to its rest position and unplug the project's line cord from the power socket. Wait a few minutes and reconnect the project to the ac power source. Depress the view pushbutton switch once more. A readout of 000.1 hour on the LED display confirms that the battery-powered memory-backup circuit is working.

Finally, apply ac power to the styli timer and to the audio system. Place the preamplifier's mode selector switch in the phono position, leaving the tonearm in its rest position. At the end of an hour, press the view pushbutton switch. If the display still reads an elapsed time of 000.1 hour, the project is not falsely counting the 60-Hz power-line frequency. If a false count is indicated, reroute any ac line cords passing near the project's audio input jack. Also, check the audio cables shield and the connections between the shield and phono jacks. Grounding the metal enclosure to the audio system's ground at only one point will also help keep 60-Hz ac out of the high-gain stages of the timer. Repeat the test procedure to ensure that the false-count problem has been solved.

Knowing the playing time of the stylus to the nearest hour or even ten hours is sufficient for replacement purposes. Contact the manufacturer of your cartridge for the recommended stylus replacement interval. If this information is not available, check spherical stylus after about 200 hours, elliptical stylus after 500 hours, and Shibata and similar stylus after 900 hours. Use a stylus microscope for making visual inspections. In double about replacement, consult a dealer.
A WIRELESS IDLE TACHOMETER FOR AUTO TUNE-UPS

Eliminate risk of damage to electronic ignition systems

BY JOHN E. DAVIS

PERFORMING your own automobile tune-ups can be a source of personal satisfaction as well as a way to save money, but if you own a late-model car with electronic ignition, you'll find that the process is not what it used to be. Many modern ignition systems are magnetically triggered and have no points to adjust, thus relegating dwell meters to museums. However, the anti-pollution devices on modern engines have made idle speed considerably more critical than it once was, so an idle tachometer is still required. Since some of these systems can be severely damaged by momentarily grounding the tachometer tie-in point, the problem is where and how to connect the tach without damaging the ignition module.

The best way would be to avoid electrical interconnection with the ignition system entirely, and you can achieve this by building the Wireless Idle Tachometer described here. The tachometer is designed to operate with any four-, six- or eight-cylinder, four-cycle engine having spark ignition. It can be used with two-cycle engines, but the meter indications will be twice the actual engine speed.

Idle tachometers generally indicate from 0 to 1000 rpm. However, partly for ease of calibration it was decided to extend the range of the tachometer described here to 2000 rpm.

Circuit Operation. The tachometer circuit (Fig. 1) uses a two-transistor monostable as a frequency-to-current converter. The input signal is radiated from the ignition system and picked up on a small telescoping (portable radio-type) antenna nearby; the output is displayed on a meter.

Under quiescent conditions, Q1 is off and Q2 is on. Since the collector of Q2 is low, there is not enough voltage to forward-bias series-connected diodes D3 and D4 and produce a current through R10, R11, and M1.
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When the antenna picks up a positive-going ignition signal, \( Q1 \) turns on and forces \( Q2 \) to turn off for an interval determined by the time-constant of \( C1 \) and the resistance selected by switch \( S2 \). The choice of time constant sets the tach for 4-, 6-, or 8-cylinder engines.

When turned off, the collector of \( Q2 \) rises to deliver a constant-voltage, constant-duration pulse to the meter network. Meter \( M1 \) will indicate the current flow. When each positive-going pulse finishes, \( Q1 \) turns off, restores to its cutoff state, and \( Q2 \) reverts to its conducting state. This stops generation of the meter pulses. As the ignition system rapidly cycles on and off, the two-transistor circuit will follow, and the meter needle will flutter. This is prevented by \( C2 \) which smooths the current pulses.

Potentiometer \( R11 \) provides means to compensate for errors due to ambient temperature variations. For example, if the ambient temperature is 20° F different from the temperature at which the tachometer was calibrated, an error of about 25 rpm will be found. If you are not overly concerned about temperature variations, use a fixed 2,200 ohms for \( R11 \).

Resistor \( R8 \), in conjunction with zener diode \( D1 \), maintains a constant 8 volts for the circuit. Switch \( S1 \) is the on/off switch. Diode \( D2 \) protects \( Q1 \) from negative spikes, while \( R3 \) provides the necessary feedback.

**Construction and Calibration.** Circuit layout is not critical and the builder may use point-to-point wiring on perf board or the printed circuit board shown in Fig. 2. Meter \( M1 \), switches \( S1 \) and \( S2 \), and control \( R11 \) are mounted on the top panel of the case. Capacitor \( C2 \) is mounted directly on the meter terminals. The two-conductor power cable exits the case where convenient.

**Parts List**

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0.47-μF capacitor</td>
</tr>
<tr>
<td>C2</td>
<td>47-μF electrolytic</td>
</tr>
<tr>
<td>D1, D2, D3, D4</td>
<td>Silicon diode (1N914 or similar)</td>
</tr>
<tr>
<td>M1</td>
<td>200-μA meter</td>
</tr>
<tr>
<td>Q1, Q2</td>
<td>2N3391A transistor</td>
</tr>
<tr>
<td>R1, R2, R9</td>
<td>1-kΩ, ½-W resistor</td>
</tr>
<tr>
<td>R3</td>
<td>47-kΩ, ½-W resistor</td>
</tr>
<tr>
<td>R4</td>
<td>10-kΩ, ½-W resistor</td>
</tr>
<tr>
<td>R5, R6</td>
<td>25-kΩ, mini-pc potentiometer (Radio Shack #271-336 or similar)</td>
</tr>
<tr>
<td>R7</td>
<td>10-kΩ, mini-pc potentiometer (Radio Shack #271-335 or similar)</td>
</tr>
<tr>
<td>R8</td>
<td>200-I, 2-W resistor</td>
</tr>
<tr>
<td>R10</td>
<td>15-kΩ, ½-W resistor</td>
</tr>
<tr>
<td>R11</td>
<td>5-kΩ linear-taper potentiometer</td>
</tr>
<tr>
<td>S1</td>
<td>Spst toggle switch</td>
</tr>
<tr>
<td>S2</td>
<td>Three-position rotary switch</td>
</tr>
<tr>
<td>Misc.</td>
<td>Telescoping portable radio antenna, suitable plastic enclosure, two-conductor power cable, battery connector, etc.</td>
</tr>
</tbody>
</table>

**Fig. 1.** The tachometer uses a two-transistor monostable circuit as a frequency-to-current converter.

**Fig. 2.** Etching and drilling guide (top) and component layout diagram for a printed-circuit board for the tachometer.

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SIMPLE MEMORY ADDITION FOR TRAINING COMPUTERS

Substitute RAM for ROM

Most one-board computers, particularly those intended for microprocessor training, contain an operating system and/or a limited high-level language in ROM and some small amount of user RAM. This RAM is usually sufficient to use the system for training purposes; but, after one becomes proficient, the need often arises for more user-memory space. Some systems provide for outboard memory but many do not. Although designed for the Heathkit ET-3400/ETA-3400 Computer Trainer/Trainer Accessory, the memory-expander approach described here can be adapted to other systems.

In this particular system, the Trainer Accessory contains Tiny BASIC in a 2K ROM. If this ROM is replaced with RAM, an additional 2048 bytes of user memory becomes available. If desired, the Tiny BASIC can be recorded on cassette and re-entered at any time using conventional cassette techniques.

Since the ROM is already placed in the system memory map, the address locations for the new RAM are safe. In actuality, the RAM connects to the system via the old ROM socket, thus no extensive wiring is required.

The 2114 static RAMs used in this project are 1K-x-4-bit types that have 1024 addresses with each addressing a
memory addition

4-bit word. Thus, four 2114 RAMs create a 2048-x-8-bit memory.

In the ETA-3400, Tiny BASIC ROM pins 1 through 8, 22, and 23 are analogous to pins 1 through 7, 15, 16, and 17 of a 2114 RAM. On the ROM, pins 9, 10, 11, and 13 through 17 are the eight data I/O pins, while pins 11 through 14 are the four data I/O pins on the 2114. Pins 21 (CS3) and 20 (CS4) on the ROM are chip-select that are placed high (pin 21) and ground (pin 20) in the Heath System. These pins can be ignored since the 2114 RAM uses pin 8 (chip select) that is analogous to pin 18 (CS2) on the ROM.

When the ROM is addressed, a circuit within the ETA-3400 decodes address lines A10 through A15 and places a low at CS2 (pin 18) when the appropriate high addresses, A10 through A15, occur for any memory locations within the ROM. Since the CS2 pin goes low for all 2K locations contained in the ROM, this line must be further decoded so that it goes low separately for the first and last half of the 2K locations. When the decoded input for the first half of the 2K locations goes low, the first half of the replacement 2K RAM is addressed; and, when the decoded input for the second half of the 2K locations goes low, the second half of the replacement RAM is similarly addressed.

The modification can be wired on a “solderless socket” having room for four 18-pin 2114s and one 14-pin 7400 TTL chip. Mount the ICs on the board with one unused row of connections between the ICs. Sockets are optional.

The 24-pin Rom socket connector is formed from a 24-pin DIP header. If such a header is difficult to locate, two 16-pin DIP headers can be suitably cut and cemented together in such a way as to form one 24-pin device.

The upper row of connectors on the solderless socket is connected to pin 24 on the 24-pin header to supply +5 volts to the RAM system. The bottom row of connectors on the solderless socket is connected to pin 12 on the 24-pin header to supply −5 volts (ground). The 2114 RAMs, ICl through IC4, have their pins 9 connected to the ground line and their pins 18 connected to the +5-volt line. Pin 7 of IC5 is connected to ground and pin 14 to −5 volts.

The five ICs are wired in accordance with Fig. 1 and connected to the 24-pin header as shown. Use lead lengths long enough to reach the ROM socket in the ETA-3400. The address and data busses shown in Fig. 1 are for the RAM addition and are not the system busses. For example, pins 17 of IC2 and IC4 are connected to A0 (address line 0) as do pins 1 of IC1 and IC3.

The CS2 modification is implemented by IC5 as shown in Fig. 1. In the Heath system, the line goes low for memory locations 1C00h through 23FFh. Address line 10 in the accessory is high for the first half of these locations (1C00h through 1FFFh) and low for the remaining locations between 2000h and 23FFh. Thus, in the IC5 stage of Fig. 1, the output from pin 8 is negative for locations 1C00h through 1FFFh while the output from pin 6 is negative for locations 2000h through 23FFh.

Only two connections must be made to the computer accessory. First, pins 1, 2, and 9 of IC5 are connected (soldered) to A10 on the 40-pin connector of the accessory (pin 18 on the Heath 40-pin connector). Second, the r/w pin for the 2114 is pin 10. Interconnect pin 10 of each 2114 then connect them together via a length of wire to pin 10 of any one of the eight 2114 RAMs in the memory accessory.

wireless tachometer (Continued from page 102)

The antenna can be mounted in any part of the case where space allows, with a hole drilled so that the antenna can be extended. If you use a plastic case, it isn’t necessary to insulate the antenna. If a metal case is used, insulation will be required whenever the antenna connects to, or passes through, the cabinet.

Calibration requires a 12-volt dc power supply (or a car battery), a 12-volt transformer, and a capacitor (approximately 0.01 µF). These components are arranged as illustrated in Fig. 3.

Turn the tachometer on and allow a few minutes for temperature stabiliza-

Fig. 3. Use this circuit to calibrate the tachometer.

The other scales will also be correct, since R11 adjusts all three scales simultaneously. Potentiometers R5, R6, and R7 should not be readjusted for temperature compensation.

Use. With the vehicle engine running, hook the tachometer power leads to the car battery, turn it on, wait approximately one minute, then extend the telescoping antenna. Set cylinder-selector switch S2 to the proper setting and hold the antenna about one or two feet over the engine. You should get a stable indication of engine rpm. If the display is erratic and the needle jumps around, there is insufficient coupling between the ignition system and the antenna. This is most likely to occur when the car’s ignition wires are concealed by the air cleaner or some other metallic element. If this is the case, move the antenna closer to the ignition coil or distributor. If you get no meter display, the power leads of the tachometer may be reversed. This will keep the unit from operating, but won’t damage it. Once you get stable readings, you can tune your car accurately and be confident that you won’t “blow” costly ignition parts.
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A LOW-COST ELECTRONIC RINGER FOR TELEPHONE LINES

Solid-state circuit can replace the electromechanical ringer in a telephone

BY BRADLEY ALBING

RECENT FCC rules changes allow users to connect electronic devices of non-Bell manufacture to telephone-company lines. One such device is the low-cost Electronic Ringer. Like a standard electromechanical ringer, it generates bursts of sound when triggered by ring pulses. However, it is not physically bulky and doesn't load down the telephone line. The sound it generates can be modified in several respects to suit the user's taste and to help him differentiate activity on one telephone line from that on another. The Electronic Ringer can also be used to actuate external devices in response to an incoming call. Several optional circuits for this application will be described.

About the Circuit. The schematic diagram of the Electronic Ringer appears in Fig. 1. At the onset of an incoming telephone call, an ac signal is applied between the green (tip or T) and red (ring or R) wires of the telephone line. This signal, which has an amplitude of approximately 90 volts root mean square and a frequency of between 20 and 40 Hz, is capacitively coupled to optoisolator IC1. The input network comprising R1, R2, C1, D1, D2 and IC1 minimizes the line loading and imbalance that simpler ring-detection circuits can cause. Diodes D1 and D2 are included to suppress "dial tapping"—the tendency of rotary-dial pulses to actuate the ringer circuit.

Fig. 1. Schematic diagram of the Electronic Ringer. Optoisolator IC1 couples ring pulses from the telephone line to the detector circuit.
Output pulses from IC1 are applied to IC2B, which squares and passes them to one input of NAND gate IC2A and to the delay network consisting of R4, D3, C3 and R5. This network furnishes additional protection against dial tapping. Capacitor C3 is initially discharged, so pulses of sufficient quantity or energy or both must be integrated by C3 to cause the output of IC2A to change state. The pulses generated by a rotary-dial telephone are neither sufficiently numerous nor energetic. Potentiometer R4 determines the charging time constant (delay time), and resistor R5 discharges C3 shortly after the end of the input pulse train.

The output of IC2A, designated the RP (RING PULSE) OUTPUT, is inverted by IC2C and applied to the RESET input of 555 timer IC3 (pin 4). The timer is connected as a gated astable multivibrator. Its RESET input is normally at logic 0, which prevents the timer from oscillating. When ring
telephone ringer

Components denoted by an asterisk comprise the optional circuits shown in Figs. 3, 4 and 5.

C1—0.47-µF, 200-V Mylar capacitor
C2—330-µF, 25-V ceramic capacitor
C4, C9*, C11*, C14*—0.01-µF, 25-V disc ceramic capacitor
C3—6.8-µF, 16-V tantalum capacitor
C5—10-µF, 16-V tantalum capacitor
C6—0.02-µF, 25-V disc ceramic capacitor
C7—1000-µF, 35-V aluminum electrolytic
C8—100-µF, 35-35-V aluminum electrolytic
C10*, C12*, C13*—1-µF, 16-V tantalum
D1—1N4003 rectifier
D2, D3, D8*, D9*, D10*, D11*, D12*, D13*—1N814 silicon switching diode
D4, D5, D6—1N400 rectifier
D7—1N5738 12-V, 1/2-W zener diode
F1—1/4-A, fast-blow, type 3A fuse
IC1—4N33 optoisolator
IC2—CD4011 quad two-input NAND gate
IC3—NE555 timer
IC4*, IC6*—CD 4516 four-stage, up/down programmable binary counter

**PARTS LIST**

IC5—74C04 hex inverting buffer
IC7*—74C154 4-line-to-16-line decoder/demultiplexer
K1*—12-V dc spdt relay
Q1—D40K1 or equivalent npn silicon power transistor
Q2—2N3904 or equivalent npn silicon switching transistor

The following, unless otherwise specified, are 14-µA, 10% tolerance, carbon-composition fixed resistors.
R1, R2—36,000 ohms
R3—100,000 ohms
R4, R8—500,000 ohms
R5—270,000 ohms
R6, R12*, R15*, R18*, R20*, R22*—1000 ohms
R7—1000-ohm linear-taper pc-mount trimmer potentiometer
R9, R10, R14*—3300-ohm linear-taper pc-mount trimmer potentiometer
R11—270 ohms
R13*, R19*—220,000 ohms
R16*, R17*—50,000-ohm linear-taper, pc-mount trimmer potentiometer
R21—4.7-megohms
T1—24-V, 500-mA center-tapped step-down transformer

Misc—Printed circuit or perforated board, IC sockets or Molex Soldercons, fuseholder, line cord, strain relief, suitable enclosure, standoffs, terminal, strips, suitable connectors, two-conductor cable, hookup wire, solder, etc.

Note—The following is available from BFA Electronics, Box 212, Northfield, OH 44067:* Kit of parts for the basic Electronic Ringer project (Figs. 1 and 2) excluding the dynamic speaker, No. ER-Kit, priced at $25.00 plus $2.00 postage and handling for U.S.A. Also available separately is an etched and drilled printed-circuit board (Fig. 6), for $6.00 plus $1.00 postage and handling for U.S.A. orders. Ohio residents, add state sales tax.

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**pulses are received, the reset input is switched between logic 0 and logic 1 by IC2C, and the multivibrator produces bursts of oscillation at a rate determined by the frequency of the pulse train. The output of the timer is a square wave whose frequency (nominally 1 kHz to 2 kHz) is determined by potentiometer R8. The square wave appears at pin 3 and is coupled to driver transistor Q1 via volume control R7 and resistor R10. The transistor alternately saturates and cuts off at an audio rate and causes a square-wave current to flow through the voice coil of the dynamic speaker.**

Power for the Electronic Ringer is provided by the supply shown in Fig. 6. **Fig. 6. Etching and drilling guide for pc board.**

---

2. Line-voltage ac is stepped down by T1 and full-wave rectified by D4 and D5. Capacitor C7 filters the output of the rectifier into an unregulated +17 volts dc. This voltage is applied to one side of the voice coil of SPKR and to the voltage-regulating network D6, C8, R11 and D7. This network provides a 12-volt dc, regulated, to the rest of the circuit. Note that the supply lacks a switch; in use, the project should be powered continuously.

**Circuit Options.** The pitch of the Electronic Ringer's tone signal can be varied by means of potentiometer R8, and its volume by means of R7. Further modification of the tone is possible by use of the circuit shown in Fig. 3. The output from IC2A clocks four-bit binary counter IC4, which generates output pulse trains at one-half, one-fourth, one-eighth and one-sixteenth of the input signal frequency. One of these outputs can be fed back to the input of IC3 by means of the network R16, R17, D9, D10 and R15 to shift the frequency of the timer's square-wave output. The high- and low-frequency tones can be adjusted independently by means of R16 and R17. At the end of each burst of ring pulses, counter IC4 is reset by the network D8, R12, R13 and C10.

The R output can be used to drive...
telephone ringer

other circuits, such as those shown in Figs. 4 and 5. External devices can be actuated by means of the circuit shown in Fig. 4. The network D11, R18, R19 and C12 integrates the RF output into a dc level that is inverted by IC5A. This inverting buffer provides base drive to Q2 when its output is at logic 1. When the transistor receives base drive, it conducts and sinks current for the coil of relay K1. The contacts of this relay can control an external electronic circuit or electromechanical device.

In the more complex circuit of Fig. 5, the RF output is processed by an input network similar to that of Fig. 4. The output of inverting buffer IC5A, however, drives four-bit binary counter IC6, whose four output lines are connected to the address inputs of demultiplexer IC7. Fifteen of the demultiplexer's output lines are employed in this project. Each in turn changes states when the appropriate number of pulses of clocks count counter IC6. A selected demultiplexer output can be connected to a driver/relay circuit or similar interface. If this is done, an external circuit or device will be actuated after the appropriate number of rings.

Construction. The Electronic Ringer can be assembled on either a printed-circuit or perforated board. Full-size etching-and-drilling, and component-placement guides for a suitable pc board appear in Figs. 6 and 7, respectively. The board contains a kludge area at one end within which circuit options can be installed. If the existing ringer of a standard 500-series desk telephone is removed, this pc board can be installed inside the telephone enclosure. Alternatively, a custom enclosure can be used.

The project's power supply should be isolated from the telephone to prevent stray pickup of 60-Hz ac radiated by the power line and the step-down transformer. A two-conductor cable can be used to connect the T and R input terminals of the project to the green and red wires, respectively, of the telephone line. If desired, telephone-type connectors can be used to facilitate interconnection of the project and the line.

If the project won't respond to incoming calls or if dial tapping occurs, reverse the T and R connections. Also, reverse the polarity of the connections between power transformer T1 and the ac line cord.

TRUTH TABLE QUIZ

BY ROBERT P. BALIN

A TRUTH Table indicates how a gate or combination of gates, responds when level 0 and level 1 signals are applied to its inputs. The table present the kind of concise picture of a circuit's characteristics that we need to apply it to solving logic problems.

To test your ability for making a truth table, determine if the output at D on each of the circuits (1-10) below is a 1 or a 0 for each of the seven arrangements shown in the table at top left. The answers are in the truth table at bottom of page.

ANSWERS: [Table of answers]

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A "SMART" GREENHOUSE LIGHT CONTROLLER

Grow temperamental plants with artificial light when the sunlight goes away

BY MARK L. McWILLIAMS

WITH their controllable growing conditions, greenhouses and hot frames can make possible the cultivation of plants too delicate to survive the rigors of the natural environment in many parts of the northern Temperate Zone. Well-established technologies for the control of temperature and humidity exist, but photoperiod (the time for which the plant is exposed to light) and the intensity of light in its duration are also important, if not critical, to plant growth. Lamps whose spectral output is consistent with plant needs exist; the problem is how to control them.

To allow the lamps to run for a fixed period of time regardless of whether the sun is hidden or not is unacceptable. For one thing, some plants would be subject to excessive illumination, and, for another; heat build-up could stress the temperature control system. Turning the lamps on when the sun is hidden and off when it reappears would be an improvement, but this too is subject to difficulties. One is that temporary occultations of the sun, as by passing clouds, birds, or aircraft, would cause an excessive number of on-off cycles and adversely affect lamp life.

An acceptable controller would give positive control of the duration of the photoperiod, turn on the lamps if the sun were to disappear for any significant length of time, and ignore short-term solar "dropouts." The system described in this article has these attributes.

Overall operation of the controller is shown in Fig. 1. The photoresistor monitors the sun's light and produces a voltage drop across its associated series resistor that is compared against a value set by the sensitivity control. If the light intensity, hence the voltage applied to the comparator non-inverting input, is too low, the comparator will trigger timer 1. This timer will delay for a preset interval (up to 10 minutes or so) to determine if the light intensity remains low. Thus, momentary blockages of the sun won't cause the lamps to turn on. If allowed to time out, timer 1 will trigger timer 2, which will turn on the lamps for some minimum time (for example, 30 minutes), but will also keep the lights on as long as the sun remains hidden.

If it has finished timing-out, when the sunlight returns, timer 2 will trigger timer 3. This timer will keep the lamps on for some period (15-20 minutes) to make sure that the sun is back to stay. If it is, the lamps will turn off when timer 3 times out. If not, the comparator will trigger timer 1, and the whole cycle starts again. (If timer 1's delay is sufficiently less than that of timer 3, the lamps will stay on after the timer 3 period times out if the sun is hidden again.)

Circuit Operation. The complete circuit is shown in Fig. 2. Photoresistor PC1's resistance can range from a few hundred to 100,000 ohms or more depending on how much light falls on it. However, only 20 to 50 ohms difference was found when a bright sunny day was compared to an overcast day. To detect such a very small difference, comparator IC1 is used. With S3 in its normal position, the voltage drop across R3 is compared against that set by sensitivity control R1.

When the light is relatively dim, the IC1 output at pin 2 goes low, thus triggering timer 1 (IC4A) via IC3. When the light is relatively dim, the IC1 output at pin 2 goes low, thus triggering timer 1 (IC4A) via IC3. The ICl output is inverted by IC2A and applied to one input of AND gate IC3. Resistor R2 acts as feedback to improve the IC1 switching action.

Timer 1 (IC4A) is one-half of a 556 operating in its one-shot mode. When it times out, its output at pin 5 is inverted by IC2B and fed to the other input of AND gate IC3. When both inputs to IC3 are high, the gate triggers timer 2 (IC5A), via inverter IC2D. Thus, two conditions are necessary to trigger timer 2—low ambient light and the timing-out of timer 1.

Timer 2 (IC5A) will turn on for a
minimum period determined by \( R15 - C11 \). However, this timer will stay on indefinitely as long as the light impinging on \( PCI \) is low, since the ICl output will remain low, and as long as it is low, timer 1 (IC4A) will not be released from its timing cycle. Capacitor \( C14 \) will keep timer 2 on even after it has timed out for as long as timer 2 is in its "on" state, it will energize relay \( K1 \) via \( D1 \) which, in turn, supplies ac power to lamp socket \( S01 \). After timer 2 turns off, it triggers IC5B timer 3 via \( C13 \). This timer remains on for a period determined by

---

**PARTS LIST**

- \( C1,C3,C5,C6,C8,C9,C10,C12,C13,C14 \)—0.01-µF disc capacitor
- \( C2,C4-100-µF \) electrolytic
- \( C7-220-µF \) electrolytic
- \( C11-1000-µF \) electrolytic
- \( D1,D2-1N4001 \) diode
- IC1—LM339 quad comparator
- IC2—7404 hex inverter
- IC3—7408 AND gate
- IC4,IC5—556 dual timer
- J1—2-conductor jack
- K1—Solid-state relay (Radio Shack 275-236)
- LED1—20-mA light-emitting diode
- PC1—CdS photos resistor (Radio Shack 276-116)

Following are 1/2-W, 10% resistors unless otherwise specified

- \( R1-5-\text{kΩ} \) potentiometer
- \( R2-10 \text{ MΩ} \)
- \( R3,R14-1 \text{ kΩ} \)
- \( R4,R6,R9,R10,R16,R17,R18-10 \text{ kΩ} \)
- \( R5-100 \text{ Ω} \)
- \( R6-120 \text{ Ω} \)
- \( R7,R13,R15-1 \text{ MΩ} \) mini-potentiometer (Radio Shack 271-229)
- \( R11,R12,R20,R21-1 \text{ MΩ} \)
- \( R19-270 \text{ Ω} \)
- \( S1-4 \)-pole, 2-position rotary switch (Radio Shack 275-1384)
- \( S2,S3-Dpdt \) miniature toggle switch (Radio Shack 275-620)
- Misc.—Sockets for ac, IC mounting sockets, case (Radio Shack 270-627), pc board, wire, solder, 6-volt battery eliminator, etc.

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**Fig. 2. Schematic diagram of the complete timer circuit. Points marked +V can be connected to a 6-volt battery eliminator or a separate 6-volt supply can be built and mounted in the enclosure.**
**R13-C7.** Timer 3 also energizes the relay via **D2.**

When timer 3 times out, relay **K1** is de-energized if the **IC1** output went high since timer 3 started. However, if the low light condition returned and **IC1** went low again, timer 1 will turn on again, and the cycle starts over. If timer 1's delay is sufficiently less than timer 3's, timer 2 will turn on before timer 3 can time out and the relay will remain energized.

**IC4B** is used as a switch debouncer, and prevents timers 2 and 3 from being triggered when the power is first applied. This timer is used to momentarily reset both halves of **IC5** (via **C9** and **C12** during the one second or so period just after the power is applied to the circuit.

A conventional 6-volt battery eliminator can be used to supply the 45 or 70 mA needed by the circuit. A 24-hour clock timer can then be used to power the battery eliminator so that the light controller operates only during daylight hours.

Switch **S7** places the controller into either TEST or OPERATION status. The only difference between these two conditions is that the timer delays are only a few seconds in the TEST mode. This latter mode is used mainly to adjust sensitivity control **R1.** **LED1** will glow in TEST so the lamps do not have to be connected to **SO1.** When the unit is not in the test mode, the LED will not operate.

Switch **S3** permits the unit to be used for much more than just a light controller. For initial testing as a light controller, **S3** should be positioned as shown with **R3** grounded.

**Construction.** The controller can be built on perf board, or a pc board can be fabricated. Sockets can be used for the ICs if desired. Once built, the circuit can be mounted within a selected enclosure with only the three switches, **R1, J1, LED1,** and lamp power socket **SO1,** mounted on an outside surface. A 6-volt power supply can also be mounted within the enclosure. The ac power line can exit via a grommeted hole at the rear.

**Adjustment.** Plug the photoresistor into **J1,** and place it so that its lightsensitive surface is receiving direct sunlight. Place **S1** in the TEST position, then **S2** to reset, then **RUN.** Adjust **R1** in small steps until a small amount of shade caused by your hand (12 or more inches away from **PCI**) causes **LED1** to turn on. Allow sufficient time between each **R1** adjustment for timer 1 to time out. If it does not time out, place **S2** in **RESET,** back **R1** off, and try again.

When you have adjusted **R1** to your satisfaction, place **S1** in the OPERATION position and connect the lamps to **SO1.** Control **R1** may have to be re-adjusted under actual overcast conditions. Note that a little hysteresis is present in **IC1** and if **R1** is adjusted "too tight", the controller will not turn the lamps off even when full sunlight appears.

While it was designed primarily as a light controller, the unit can be used to control other ac loads depending on the type of sensor plugged into **J1.** For example, replacing **PCI** with a temperature sensor, the controller could be used to turn on heating elements after ignoring momentary high temperatures. Using the same probe but placing **S3** in the REVERSE position, which switches the relative positions of **R3** and the external probe in their voltage divider configuration—the controller can be used to turn on exhaust fans while ignoring sudden low temperatures.

It is possible that some user modification of potentiometer **R1** and **R3** might be necessary if probes having different resistance characteristics from those of **PCI** are used. Also, if even the small amount of hysteresis present in **IC1** cannot be tolerated, experiment with different valued resistors for feedback resistor **R2.**
The LM 339

A Great Comparator

Four independent comparator circuits on one chip can be used in a variety of analog and digital applications

BY CLEMENT S. PEPPER

The key word to describe the 339 quad comparator is versatility. This device can interface a slow-moving analog signal to almost any logic family, will drive a LED, detect high- and/or low-voltage limits and can be used as a monotable oscillator.

What makes the 339 so versatile? Consider its power requirements as an example. The chip will work from a single dc source between 2 and 32 volts, or a split power supply from ±1 to ±18 volts. Current drain is a meager 0.8 mA, independent of supply voltage.

The common-mode range includes ground, even when operated from a single supply. With a typical input bias current of 25-nanoamperes, a 3-nanoamper offset and a 3-mV input offset voltage, the input can “look” at almost any source impedance without loading.

The 339 output stage is an npn transistor having an uncommitted collector so that an external pullup resistor can be used with a supply voltage different than that used by the remainder of the device. You can even hard-wire the outputs in an OR configuration. The transistor output stage will sink up to 20 mA, but you may have to live with a high saturation voltage (with 4 mA it is 250 mV). The output is compatible with TTL (fan-out of 2), DTL, ECL, MOS and CMOS.

The 339 chip contains four identical comparators, and is available from many parts suppliers at prices as low as $1 each.

Device Operation. The pinout for the 339 is shown in Fig. 1A. The numbers across each row indicate the noninverting and inverting inputs with the associated outputs for each of the four comparators in the chip.

A basic comparator is shown in Fig. 1B. Here, the input signal V\textsubscript{IN} is compared with a fixed reference V\textsubscript{REF}. Whenever the input signal exceeds the reference level by just a couple of milivolts, the output (V\textsubscript{O}) goes high. This action is illustrated by the associated waveforms.

Unfortunately, such a basic circuit can oscillate during the transition period, and although this might present a problem with slow analog signals, it would cause no trouble for the fast transition times associated with digital signals. This can be averted by using a small amount of positive feedback as shown in Fig. 1C. The feedback not only speeds up the transition, but adds a little hysteresis.

Feedback resistor R\textsubscript{F} is typically a high value, 10 megohms for example.

While hysteresis can eliminate the transient oscillation, it can also be put to work in a useful manner such as “cleaning up” input waveforms, acting like a Schmitt trigger. However, most Schmitt triggers lack adjustability, and further along in this article, we will illustrate a 339 Schmitt trigger that does not have this problem.

Analog-to-Digital Interface. The input for a frequency counter is a good example of an analog-to-digital interface (not to be confused with an A/D converter as used in computers).

The input of a frequency counter must be capable of accepting a wide variety of signals, slow or fast, and provide a signal compatible with the digital counter circuits that follow. Also, since the input levels can span a broad range of levels, sensitivity adjustments are required. Then there must be a “threshold” established either to reject noise, or possibly to match a digital source. Such a circuit is shown in Fig. 2A.

Sine-wave performance (10 kHz) is shown in Fig. 2B with a 3-volt rms input and Fig. 2C with 1-volt rms input. This circuit has been used with excellent results to 1 MHz.

CMOS to TTL Translation. The circuit shown in Fig. 2A is also useful for translating various logic families. For this application, two series-connected 1N914 diodes may be substituted for the 2000-ohm potentiometer. This estab-
lishes a 1.4-volt reference compatible with both TTL and CMOS operating from a 5-volt supply. The 1000-ohm pullup resistor connected at the output has to be connected to the TTL 5-volt supply.

During the design of an 8-input oscilloscope circuit, the author connected eight such circuits, with all eight inputs connected to a source having a pulse 8-microseconds wide. The upper four traces of Fig. 3 came from one 339 package, while the lower four traces came from another 339 package. Actual time variations are about 200 nanoseconds. This illustrates the quality of diffusion techniques these days.

High and Low Limit Detection.
Two comparators working together sense the low and high limits in the simplified capacitance measuring scheme shown in Fig. 4A. The unknown capacitor (C) is charged from a constant-current source (I1). This results in a linear charging ramp whose slope is proportional to the capacitance (Fig. 4B). The limit voltages are 0.10 and 1.10 volts, so that the measurement becomes that of the time required to charge the capacitor to this higher voltage.

In the complete circuit (Fig. 4C), the addition of an exclusive-OR gate yields a pulse whose width is scaled to the value of the capacitor. Scope traces of a typical measurement are shown in Fig. 4D. The capacitance can be determined from the width of the pulse.

Earlier in this article, hysteresis was mentioned as one way to get high and low limit detection, such as used in a Schmitt trigger. The circuit shown in Fig. 5A uses a single comparator which does not have the precision of the dual comparator approach but is useful with looser tolerance circuits.

Although the circuit appears tricky, it is easy to understand. First, you have to know the desired upper and lower switching voltages. Then, select a zener
diode that falls midway between these voltages. Part of the problem comes when trying to get a zener diode of the correct value since zeners come in specific voltages. Therefore, pick the closest value. Select R1 for 5 to 10 mA of zener current.

When the 339 output is low, some of the current through R1 flows through R2 and R3 into the output. We can safely assume that none flows into the noninverting (+) input. Pin 5 of the 339 will now be lower than the zener.

With the 339 output high, current flows through R4, R3 and R2 into the zener diode.

Although we will not go into a detailed circuit analysis, the "trick" here is to select the resistor values. In the circuit shown in Fig. 5A, the switching points are 7.7 and 4.0 volts. Build the circuit and vary the resistor values to get a feel for circuit operation. A typical waveform is shown in Fig. 5B.

Monostable. The circuit for a 339 monostable is shown in Fig. 6A, with an output waveform shown in Fig. 6B.

The inverting (-) input of the comparator is biased about 1.25 volts positive by the 6.8-megohm and 1-megohm voltage divider.

Fig. 5. High/low limit detector (A). Waveforms (B) show switching action.

Fig. 6. Monostable circuit (A). In (B) 1710-Hz input is at top, output below (5 V/div).

Although this circuit may require some "tweaking" to achieve specific monostable action, it is useful to know about if you have an unused comparator in your design and require a monostable.
Add-on circuit monitors the output of a broadcast receiver and sounds an alarm when an EBS warning signal is received.

The National Weather Service and the Civil Defense Agency, in conjunction with local broadcasters and other authorities, maintain an emergency warning system to alert the public in case of impending natural disaster or national defense emergency. This system consists of a network of AM and FM radio stations that will interrupt their normal programs to broadcast an emergency bulletin immediately after an official severe weather or Civil Defense warning is issued. You have probably heard tests of this emergency broadcast system (EBS) on local radio stations. During such tests, and in the event of an actual alert, participating stations broadcast a special two-tone signal used to activate warning devices at other radio stations and at regional Civil Defense offices.

For less than $25.00, you can build a circuit that will respond to the EBS alerting signal. This project receives signals from the earphone jack of a standard broadcast receiver and, in response
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to the special EBS tones, actuates a Son-alert or similar audible alarm or a relay. For around-the-clock protection, the EBS Monitor and the radio to which it is connected can be left activated continuously. If an emergency occurs, the alarm could save your life.

How it Works. The EBS alert signal consists of simultaneous tones at 853 Hz and 960 Hz broadcast for 22.5 seconds. This unlikely combination of frequencies and its long duration make it easy to distinguish the warning signal from speech and music. (Its waveform is shown in Fig. 1.)

Commercial EBS alerting devices employ a separate tone decoder for each of the two audio frequencies and a time-delay circuit that triggers an alarm only when the two frequencies are present for 15 seconds or more. This is an expensive approach requiring a large battery power source. To minimize cost and battery drain without sacrificing performance, this project employs a single CMOS phase-locked loop (PLL) to detect the presence of both frequencies. Three other CMOS integrated circuits perform most of the remaining functions. The circuit, which is shown schematically in Fig. 2, is such an energy miser that it will operate in its listening mode for more than one year on a single 9-volt transistor battery.

Transistor Q1 amplifies the 107-Hz difference signal and, with the help of inverter IC3A, converts it to a square wave that is then applied to the input (pin 14) of IC4, the phase-locked loop. The loop acts as a frequency-to-voltage converter that can be programmed to respond to a narrow band of frequencies called the lock range. Over this lock range, the output (pin 9) of the phase-locked loop will be a voltage that increases as the frequency of the input signal increases. For an input frequency
outside of the lock range, the PLL output voltage will approach either 0 or 9 volts, depending on whether the input frequency is above or below the lock range. Capacitors C3 and C4, together with resistors R5, R6, and R7, and potentiometer R21 limit the lock range of the PLL to between 100 and 115 Hz. When a 107-Hz signal is applied to the input of the PLL, its output voltage will be approximately 4.5 volts. This output voltage level can, therefore, be interpreted as an indication that a 107-Hz input frequency is present.

At this point in the circuit, a network is needed that will have a logic 1 output when its input is approximately 4.5 volts, and a logic 0 output when its input is either greater than or less than 4.5 volts. Integrated MOSFETs contained in IC2 together with inverter IC3B and NOR gate IC1A form such a network. Thus, the presence of the EBS alert signal causes the output of IC1A (pin 4) to go high. However, difference frequencies close to 107 Hz that are occasionally contained in voice, music and noise can also cause the output of IC1A to momentarily go high. False alarms due to these normal audio components can be avoided by requiring that the output of IC1A be high for at least 15 seconds before the circuit triggers alarm.

This delay is obtained by having the output of IC1A charged through capacitors C1 and C6 and capacitor C7. The output from the inverter is fed to the input of the trigger. When the output of the Schmitt trigger reaches logic 1, the delay is added to the time. This delay is increased by adding logic 1 to the output of the Schmitt trigger made up of inverters IC3C and IC3D and resistors R14 and R15. The output (pin 15) of the Schmitt trigger is connected to the input of the alarm trigger flip-flop consisting of NOR gates IC1B and IC1C. When the output of the Schmitt trigger switches to logic 1, the output of the alarm trigger flip-flop (pin 10) switches from logic 1 to logic 0. Once this happens, the output of the flip-flop will remain low even if the output of the Schmitt trigger returns to logic 0.

The logic 0 appearing at the output of the flip-flop activates the oscillator made up of NOR gate IC1D and inverter IC3E. This oscillator generates a square wave that alternately turns Q2 on and off, activating alarm A1.

The circuit contains a few other components whose functions should be noted. Capacitor C6 and resistor R16 generate a positive pulse which resets the alarm trigger flip-flop each time power switch S1 is closed. This assures that the alarm will be silent when power is applied to the circuit. Light-emitting diodes LED1 and LED2 indicate when the audio output of the broadcast receiver that drives the circuit is at the proper level. The receiver's output should be adjusted so that, when test switch S2 is closed, LED1 flickers on and off but LED2 remains dark. If volume is too low, neither LED will flicker. If volume is too high, both LEDs will flicker. Diode LED3 is used to indicate when a 107-Hz signal is being detected. It glows whenever the output of NOR gate IC1A is at logic 1. Diode D4 prevents damage to the circuit that would otherwise occur if the battery leads were to become inadvertently reversed.

Construction. The EBS Monitor is most easily assembled using a printed circuit board. The full-size etching and drilling guide for a suitable printed circuit board is shown in Fig. 3. Its corresponding parts placement guide appears in Fig. 4. Mount the integrated circuits using sockets or Mallory Solderco rath-

![Fig. 2. The circuit in the project uses a CMOS phase-locked loop to detect the presence of the alert signal. The CMOS components cause little battery drain so that the monitor can be used constantly.](image-url)
er than soldering them directly to the board. This makes replacement of defective ICs infinitely easier and eliminates the possibility of damaging them during soldering. Be sure to observe polarities and pin basings when you mount the diodes, transistors, LEDs, ICs, and electrolytic capacitors.

The LEDs should be mounted off the board so that they can project through the front panel of the enclosure that is employed to house the project. The switches should also be mounted on the front panel. Connect the LEDs and switches to the pc board using flexible hook-up wire. Input jack J1 should be mounted on the rear of the enclosure and connected to the board using two-conductor cable. Fasten a retaining clip for the 9-volt battery to the enclosure and connect suitably long leads from the appropriate foil pads to a 9-volt battery clip. Then install the battery and snap the connecting clip in place. Finally, prepare a two-conductor patch cord of convenient length terminated with miniature phone plugs at each end.

Alignment. There are only three adjustments that must be made before the EBS Monitor is ready for service. Potentiometer R21 must be adjusted so that the lock range of the PLL is centered around 107 Hz. Third, potentiometer R22 needs to be set so that, once LED3 begins to glow, there will be a 12- to 18-second delay before the alarm sounds. The easiest way to make these adjustments is to first make a recording of the EBS alert signal when a local radio station is conducting an EBS test. Use a high-quality cassette or open-reel tape recorder that has an earphone or line-level output jack. After you have recorded the two-tone signal, patch the output to the project's input jack and proceed as follows.

First, connect a voltmeter between pin 14 of IC4 and the circuit ground. Then close switch S1 and play back the EBS alert signal. (Rewind and repeat this step as necessary so that the tone is present during all of the remaining steps.) Hold switch S2 closed and adjust the recorder's output level until LED1 glows but LED2 remains dark. Vary potentiometer R20 until the voltmeter reads 3 to 5 volts dc. Vary potentiometer R21 until LED3 glows most or all of the time that the tone is present. Vary potentiometer R22 until the delay between the application of the tone and the activation of the audible alarm is between 12 and 18 seconds. The delay can be reduced by moving the wiper of R22 toward capacitor C5 as viewed from the top of the board.

Use. Your EBS monitor is ready for service. Apply power to both the project and the broadcast receiver with which it will be used. Tune in a local radio station that participates in the Emergency Broadcast Service, has a strong signal in your area, and broadcasts 24 hours a day. If possible, choose an FM station, because static interference during an electrical storm will be less severe and the operation of the Monitor will be more reliable.

Patch the output of the receiver to input jack J1 and, if necessary, adjust the output level so that LEDs flickers in step with the demodulated signal when S2 is depressed but that LED2 remains dark. When the project is operating in its listening mode, LED3 should flicker on occasionally. As long as it flashes brightly, the battery is in good condition. As the battery becomes weaker and needs replacing, LED3 will diminish in brightness.

Take advantage of the broadcaster's EBS tests to check the circuit periodically for proper operation. These tests are never conducted at night, so you will not be disturbed by false alarms if you leave the project in its listening mode while you sleep. When the alarm sounds, remove power from the project and disconnect the patch cord from the output jack of your broadcast receiver. You will then be able to hear the emergency message that follows.

Fig. 3. Actual-size etching and drilling guide for a suitable printed circuit board.

Fig. 4. Component layout for the monitor's printed circuit board is shown below.
Build a Diode Temperature Probe

Low-cost sensor gives temperature reading on a DMM

**Construction.** The circuit can be assembled on a small printed-circuit or perforated board. The small circles at C1 indicate the need for a pc pad, or WireWrap pin to make the connections to the remote diode.

To make the temperature probe safe for liquid immersion, the arrangement shown in Fig. 2 is used. Preform a short length of vinyl tubing, fill it with epoxy, and "thread" it up the diode leads to make contact with the diode body. Allow the epoxy to thoroughly cure. If desired, a length of heat-shrink tubing may be used. In either case, leave a short length of diode lead exposed for soldering to the flexible cable.

Slide a short length of heat-shrink tubing over the covered diode leads, solder each diode lead to the flexible cable, and then fit the tubing over the solder joint. Shrink the tubing to make a tight fit.

**Calibration.** The resistance values for R2-R4 and R6-R7 are not critical, but their ratios are. Perform the following calibration tests before changing any resistance value.

Potentiometer R3 balances the bridge to indicate 32°F (0°C) at this temperature. Potentiometer R5 is used to reduce the 1.25 (2.24) mV/degree to exactly 1 mV/degree and is also used to set the upper range point.

With R3 and R5 at their center of rotation, immerse the diode probe in a container of finely shaved or crushed ice. Adjust R3 to produce a DMM indication of 32°F or 0°C. Place the DMM in the 2-volt dc range, immerse the probe in a container of boiling water, and adjust R5 for a DMM indication of 212°F or 100°C.

If you find that R3 is at one end of its rotation, add a parallel resistor in the megohm range across either R2 or R4, depending on the location of the wiper of R3. If R5 is at one end of its rotation, add a parallel resistor (also in the megohm range) across R6 or R7. If desired, a 10-turn trimmer potentiometer can be used for each of the fixed resistors and preset for the correct ratios.

Since the DMM will also indicate negative voltages, it will similarly indicate temperatures below those at which it is calibrated. Also, the diode can operate at temperatures above 212°F, which is about the limit for the plastic insulation used for the diode leads, so a plastic with a higher temperature rating can be used to liquid-proof the sensor. Or, without such protection, the sensor can be used for dry, or contact, temperature measurements.

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**PARTS LIST**

- C1 — 0.01-μF disc capacitor
- D1 — 1N914 silicon diode
- R1 — 33 kΩ, 1/2-W resistor
- R2 — 82 kΩ (2.24 kΩ) or 12 kΩ (C) 1/2-W resistor
- R3 — 1 kΩ pc-mount potentiometer
- R4 — 32 kΩ (C) or 68 kΩ (C) 1/2-W resistor
- R5 — 10 kΩ pc-mount potentiometer
- R6 — 49 kΩ (F) or 120 kΩ (C) 1/2-W resistor
- Misc. — 1.35-volt battery and holder, vinyl or heat-shrink tubing, flexible two-conductor cable, epoxy, solder, etc.

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Fig. 1. Diode is one leg of a Wheatstone bridge connected to DMM.

Fig. 2. To make probe immersible, vinyl tubing is added around leads.
Measure Weak Direct Currents with the Sensitive Micro Meter

BY I. QUEEN

Low-cost op-amp system can measure solar-cell output and currents in other low-level circuits.

IF YOU PLAN to measure the output of a solar cell under low-light conditions, to work with micropower ICs, or otherwise experiment with weak-current circuits, you'll need a sensitive current meter. The Sensitive µ Meter presented here will allow you to measure direct currents as small as a fraction of a microampere. Moreover, it is not subject to the disadvantages associated with standard panel microammeters—high cost, fragile movements, and relatively high internal resistance.

The project employs an operational amplifier to increase the sensitivity and effectively decrease the input impedance of a moderately priced, readily available 0-to-50 microammeter. It has three switch-selected scales; 0 to 0.5 µ A; 0 to 5 µ A; and 0 to 50 µ A. The circuit can be powered by a supply furnishing as little as ±2 or ±4 V, and can be constructed for about $15.

Circuit Operation. A simple circuit for current-measuring applications is shown in Fig. 1. When an input current I is applied to the inverting input of the op amp, an inverted output signal is generated by the op amp. If the gain of the operational amplifier is very high, we can consider that the entire input current flows through feedback resistor R. An output voltmeter M, which is calibrated in terms of I, measures the product IR. The voltage drop across the operational amplifier is practically zero (the output voltage divided by the op amp's open-loop gain).

The schematic of the Sensitive µ Meter is shown in Fig. 2. Switch S2 selects the range and determines the feedback resistance of the stage. When the switch is in its center (off) position, the feedback resistance is R3, one meg-ohm. An input current of 0.5 µ A will cause the output of the op amp to be 0.5 volt above ground when only R3 is in the feedback loop.

This output voltage will cause full-scale deflection of 0-to-50-microammeter M1 if the effective resistance between the output terminal of the operational amplifier and the negative terminal of the meter is 10,000 ohms. The internal resistance of the meter specified in the parts list is 1620 ohms, so the balance of the required resistance is supplied by R4. This trimmer potentiometer is adjusted for full-scale deflection of the meter movement when the op amp output is at +0.5 volt.

The project is most sensitive when S2 is in its center (off) position and the feedback resistance is one megohm. In this operating mode, full-scale deflection of the meter corresponds to an input current of 0.5 µ A. Higher-current ranges are obtained by shunting R3 with other resistors to lower the overall feedback resistance. This is accomplished by placing S2 in one of its two other positions. When the range switch is placed in its 5 µ a position, the parallel combination of R1 and R3 causes the meter to deflect to full scale if the input current is five microamperes. Similarly, placing S2 in its 50 µ a position shunts R3 with R2 and causes full-scale deflection of the meter movement when an input current of fifty microamperes exists.

Two shorting switches are included in the circuit. Switch S1 shorts the input of the project. It is used in conjunction with potentiometer R5 to zero the meter movement. The other switch (S3) is used to short the terminals of M1 when the meter is not being used. This minimizes mechanical shocks to the meter movement when the project is being transported. Diodes D1 and D2 protect the project from excessive input voltages. Jack J2 provides access to M1 so that the meter can be used in isolation from the rest of the project.

You might wonder why the circuit provides for a 0-to-50-microampere scale when meter movement, M1, covers this range on its own. The following exercise performed by the author will illustrate the need for such a scale. A solar cell was connected across input jack J1 and illuminated so that the Sensitive µ Meter indicated a current of 50 µ A. The cell was then connected to J2 and its output current measured using M1 alone. It indicated a current of 1 µ A.

The reason for this discrepancy between the two readings is that M1 presents a higher resistance to the solar cell when it is used independently than the project as a whole does. It is desirable to keep the internal impedance of a current-measuring instrument as low as possible. Thus, it is better to employ the project as a whole (as opposed to M1 or a similar meter alone) in the measurement of currents up to 50 µ A.

There is another significant advantage to the use of the Sensitive µ Meter as opposed to a microammeter alone. Due to the clipping action of protective diodes D1 and D2, the maximum output voltage of the op amp on any of the three ranges is

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Fig. 1. Schematic of simple current-measuring circuit.
approximately 0.7 volt. This corresponds to less than a 50% overload of meter movement M1, one that is highly unlikely to cause any permanent damage to the movement. An unprotected microammeter, on the other hand, can easily be "zapped" by the inadvertent application of high current overloads, a fact to which more than one electronics experimenter can ruefully attest.

Power for the circuit is furnished by an external supply via phone jack J3. Note that the shell of this power jack must be insulated from chassis ground. The operational amplifier specified for use as IC1 is an LM308, a precision op amp that can be used with supply voltages ranging from ±2 to ±20 volts. Accordingly, a supply capable of furnishing bipolar voltages within these extremes (or a single-ended one rated at 4 to 40 V) should be employed to power the Sensitive μA Meter. Potentiometer R5 is connected across the supply to allow zeroing of the meter movement under no-input conditions (S1 closed) for any suitable supply voltage.

Construction. The project is relatively simple, so the use of a perforated board and point-to-point wiring is an acceptable assembly technique. Alternatively, the project can be constructed using wrapped-wire or printed circuit connections. The author housed his prototype in a 4" x 2" x 1½" (10.2 x 5.1 x 3.8 cm) aluminum utility box. A Radio Shack No. 22-051 0-to-50-microammeter was used for M1. This meter fits the enclosure with only a slight amount of overlap at the edges. Of course, a larger enclosure can be employed if it is preferred over the one selected by the author.

An LM307 operational amplifier can be used for IC1 in place of an LM308 if pin 3 is connected to project ground through the parallel combination of a 30,000-ohm resistor and a 0.1-μF disc ceramic capacitor. This op amp will provide performance comparable to that of the LM308 if the circuit is modified as just described. Other operational amplifiers can also be used if variations in pinouts and possible compensation requirements are taken into account.

Calibration and Use. Connect a suitable power supply to J3, observing polarities. Then close S1, place S2 in its 0.5 μA position, and open S3. Set the wiper of R4 halfway between the two extremes of its travel and adjust potentiometer R5 for a zero reading on meter movement M1. Then open S1 and place S2 in its 50 μA position. Connect a suitable source of weak dc current to the input jack of the project using a length of shielded cable terminated with a miniature phone plug. A 1.5-volt battery and a series-connected 1-megohm potentiometer can be used as a source of low-level dc.

Depending on the capabilities and sensitivity of the test equipment available to you, monitor either the current at J1 or the voltage at the output of the operational amplifier. Adjust the amplitude of the input current so that it equals 50 μA. Alternatively, monitor the output voltage of the op amp and adjust the amplitude of the input current until the voltmeter reads +0.500 volt. Then adjust trimmer potentiometer R4 to obtain a full-scale (50 μA) reading on M1.

The Sensitive μA Meter is now calibrated and ready for use. In view of its high sensitivity, it is a remarkably stable instrument. At the start of each measuring session, the meter should be zeroed by adjusting potentiometer R5. It should not be necessary to continually touch up this adjustment if a battery or regulated line-powered supply is used in conjunction with the project.

Thanks to the protective action of D1 and D2, the meter movement is relatively immune from damage caused by current overloads. Overloads should still be avoided, however, especially severe ones that could damage the protective diodes. Finally, remember that it is good practice to keep shorting-switch S3 closed when the project is not being used. This will damp the meter movement and minimize the effects of physical shock upon it.
TWO LOW-COST AUTOMOBILE PROJECTS

1. SIMPLE LOW-COST CHARGER KEEPS AN AUTOMOTIVE-TYPE BATTERY IN PEAK SHAPE

BY CASS R. LEWART

This simple 12-volt automotive battery booster/trickle charger provides a choice of charging rates to suit battery condition. Set to FULL CHARGE, it will restore a partially discharged battery overnight; when set to TRICKLE CHARGE, it will maintain the battery at peak capacity for an extended time. A built-in LED glows only when the charger is delivering current to the battery. (The circuit is shown in Fig. 1.)

Circuit Operation. The output of \( T1 \) is rectified by diodes \( D1 \) and \( D2 \), pulsating dc is delivered to the battery via a cable to the cigarette lighter connector in the vehicle. Switch \( S1 \) is used to choose between FULL CHARGE (approximately one ampere) and TRICKLE CHARGE (50-mA). Indicator LED \( L1 \) is in series with its current limiter, \( R4 \). The fuse protects against short circuits.

Construction. The entire circuit can be mounted in a small metal enclosure, using multilug terminal strips to support the components. Point-to-point wiring can be used. The ac line cord and the output cable should be passed out of the enclosure via grommeted holes. A plug that fits the vehicle's cigarette lighter should be connected to the output cable. Make sure the polarity is correct.

Operation. Plug the ac line cord into a convenient outlet and plug the output cable into the cigarette lighter connector. Select either a FULL or TRICKLE charge via \( S1 \), and verify that the LED glows in either position of \( S1 \). If the LED does not glow, clean the contacts on the plug and the cigarette lighter and try again. If this fails, check for a wiring error. Should the battery be completely discharged (dome light does not light...
2. ALARM SOUNDS IF YOUR HEADLIGHTS OR PARKING LIGHTS ARE ON WITH THE IGNITION OFF

BY C. R. BALL

HAVE you ever walked away from your car, left your lights on, and returned later to discover that your battery has run down? The circuit described here will prevent this problem. It will sound an alarm if you turn off your car's ignition while the headlights or parking lights are on. The alarm ceases when the lights are turned off.

Circuit Operation. The circuit, shown in Fig. 1 is based on a 555 timer IC. Diodes D1 and D2 are arranged as an OR gate so that either will pass positive voltage from its anode to IC1. Diode D3 blocks reverse current when the ignition alone is on. When the ignition and either the headlights or parking lights are on, little or no potential difference exists across the powerpins of IC1, which remains inoperative.

If either the headlight or parking light circuit is alive, and the ignition line is off, the dc circuit for IC1 is complete. The oscillator starts, and sounds a warning tone via the loudspeaker. The tone's frequency may be changed by varying the values of R1, R2, or C1. Resistor R3 sets the loudness, and its value may be altered as desired.

Zener diode ZD1 may be required to provide a threshold to prevent the alarm from operating if there is a small potential difference in the dc supply circuit during normal operation. To determine the necessity and/or value of ZD1, with the headlights and ignition both on, measure the voltage between points H and I. If the voltage is more than 1.4 volts, the zener is required. The zener voltage should be slightly higher than the excess over 1.4 volts. For low voltages, one or more forward-biased silicon diodes can be substituted for the zener. Each silicon diode drops about 0.7 volt.

Construction. The system can be assembled on a small piece of perf board, or on the pc board whose foil pattern is shown in Fig. 2. After completion, the board can be mounted in a small enclosure. Check the polarities of the IC and all diodes before applying power.

The small speaker is connected to the two pads marked S, the pad marked I is connected to the vehicle ignition lead (after the ignition switch), the pad marked H connects to the headlight power line, and the pad marked P goes to the parking light line.

To allow the lights to be used with the ignition off, an spst switch can be connected in series with D3 to defeat the alarm. If this switch is used, make sure that it is clearly identified so that it can be closed for normal operation.

Fig. 1. With ignition off, and the headlights and parking lights on, alarm will sound.

Fig. 2. Etching and drilling guide and component installation is at left.
When your line voltage nosedives, this circuit gives a 6-volt boost

BY HERBERT ELKIN

D O YOUR lights go dim, does your TV picture shrink and lose brightness, or are your ac appliances acting as though they're just plain tired? You may be living in an area subject to "brownouts" (low power-line voltage), and the solution to your troubles could well be some form of voltage regulation.

The automatic line voltage regulator described in this article will automatically raise power-line voltage by about six volts whenever it drops below a preset level. When the line voltage returns to normal, the compensation automatically drops out. (See Fig. 1.)

Circuit Operation. Filament transformer T1 is connected with its 6.3-volt secondary in series with the primary so that the two voltages add. Relay K1 taps an output from the primary alone or from the combined windings. The remainder of the circuit senses the output voltage and sets (or resets) K1 to switch the extra winding in or out as needed.

As can be seen from Fig. 1 and the waveforms of Fig. 2, capacitor C1 follows the swings of the fraction of the power-line voltage developed across the R2 portion of voltage divider R1-R2. Potentiometer R2 is adjusted so that the peak voltage across C1 just reaches the firing level of neon lamp II when the voltage across R1-R2 reaches the level where automatic compensation is not required. The neon lamp breaks down and applies a positive pulse to the gate of SCR1, causing the SCR to turn on and hold relay K1 in the position that directs the normal line voltage to the output. The SCR, then turns off when the power-line voltage passes through zero. The neon lamp fires on each positive half cycle, allowing its glow to be used as a "normal" line voltage indication. During the negative half cycles, diode D1 clamps C1 to circuit ground, thus keeping the neon lamp "off" and preventing the negative pulse from being applied to the SCR gate.

Because its drive switches on and off at power-line frequency, relay K1 would normally "chatter." Capacitor C4, connected across the relay coil, prevents this problem as it charges when the SCR fires to provide both filtering (due to rectification of the ac voltage by SCR1).

*Loral Electronic Systems, Yonkers, NY.

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**PARTS LIST**

- C1, C2, C3—0.015-µF, 400-volt ceramic capacitor
- C4—4-µF, 250-volt electrolytic
- D1—1N2069, 1-ampere, 200-PIV rectifier
- F1—3-ampere, slow-blow fuse with holder
- I1—NE-51H neon lamp assembly (Dialco 95-0463-0931-211 or similar)
- K1—2pdt, 48-volt, 2500-ohm relay (Sigma 62R2-48DC-SCO or similar)
- R1—51,000-ohm, 1/2-W, 10% resistor
- R3, R4—56-ohm, 1/2-W, 10% resistor
- R5—47-ohm, 1/2-W, 10% resistor
- R2—100,000-ohm, multi-turn pot.
- S1—2pdt switch
- SCR1—4-ampere, 200-PIV silicon controlled rectifier
- T1—6.3-V 3-A, filament transformer
- Misc.—Ac recepable (SO1), terminal strip, suitable enclosure, spacers, mounting hardware, etc.
and relay-coil holding current when the SCR is off.

The networks consisting of R3-C2 and R4-C3 form arc-suppression circuits to minimize relay contact pitting, while R5 limits SCR surge current to a safe value. Using the parts shown in Fig. 1, appliances drawing up to 350 VA can be controlled. For higher power, a larger transformer and a relay with heavier contacts can be used. Make sure that fuse F1 is a slow-blow type to accommodate any turn-on surge currents. To bypass the compensation circuit, switch S1 can be set to OFF.

Construction. With the exception of transformer T1, output socket SO1, neon lamp assembly II, and on/off switch S1, all components can be mounted on a small pc board—or a perf board, using point-to-point wiring. The board can be mounted in any type of enclosure that can accommodate all of the components. The line cord exits through a grommeted hole.

A terminal strip with nongrounded lugs must be used for the transformer leads and ac power connections. If a metal enclosure is used, it is important that it be isolated from both sides of the power line to prevent a shock hazard.

The windings of T1 can be phased using the setup shown in Fig. 3. Temporarily connect one secondary lead to one side of the primary as shown. Very carefully (to avoid shock), measure and note the voltage appearing across the transformer primary alone. This is the line voltage. Then measure the voltage across the combined primary/secondary and note that it is 6.3 volts higher. If the voltage indication is less than the noted line voltage, phasing is incorrect. Exchange the two secondary leads and repeat the above test. When the combined voltage is higher than the line voltage, you know that the transformer leads are properly phased.

Calibration. To adjust the low-voltage trip point, a source of variable line voltage is required. (A Variac or similar device will do.) Adjust the power-line input for 110 volts—or whatever voltage you wish the relay to trip at—and connect an ac voltmeter across the contacts of SO1. Vary potentiometer R2 until neon lamp II glows and note that as this happens the relay is activated, which means that the voltage is not boosted, and the ac voltmeter across SO1 registers 110 volts.

Carefully rotate R2 until the neon lamp just extinguishes and the relay de-energizes. The ac voltmeter across SO1 should move up to approximately 116.3 volts. Slowly increase the input voltage until the neon lamp lights and note that the ac voltmeter indicates about 112 volts. Set the trip point wherever you want it to occur.

In Conclusion. This project represents a simple, inexpensive way to provide some compensation for low power-line voltage. Its regulation is somewhat coarse, but is sufficient for most home appliances. Note that, since relay K1 interrupts power briefly while switching in the booster winding, the circuit may not be suitable for use with sensitive devices such as computers or digital clocks.
A low-cost circuit provides up to 16 logic displays on single-trace oscilloscopes

HOW ORDINARY OSCILLOSCOPES CAN DISPLAY MULTI-CHANNEL LOGIC SIGNALS

By Les Solomon

Digital logic circuits, whether they are in a simple counter or a complex computer, are formed from interlocking networks of gates and flip-flops. Observing such circuits as they operate is possible with a logic probe, a dc voltmeter, or a scope. But since a logic probe or voltmeter can monitor but one signal at a time and the operation of digital circuits depends on the time relationships between a large number of signals, these instruments are of little help. A dual-trace scope does little better as it can be used to monitor only two signals.

What is needed is a way to monitor many signals simultaneously. The obvious solution, a logic analyzer, is costly. However, by taking advantage of some low-cost, readily available ICs, it is possible to construct a very inexpensive logic state analyzer that can display eight vertically displaced discrete traces on a conventional single-trace scope. Each trace will display the signals present on a selected input line. Thus, the timing of up to eight different points within a circuit can be simultaneously observed. The basic circuit is shown in Fig. 1.

Circuit Operation. The “heart” of the circuit is a 1-of-8 data selector that can accept eight TTL inputs and, via an internal address decoder, place one of the eight at a time on the chip output line. The inputs are selected by applying a digital code from 000 to 111 to the three address inputs of the data selector. When the enable pin (7) is held low, the chip operates normally.

The three address lines are driven from a counter (a divide-by-sixteen 7493, a decade 7490, or almost any other counter). When the clock input is driven, the three address outputs cycle continuously through the digital code.

The eight traces are developed from the three address lines by a rudimentary D/A converter formed by R1, R2, and R3 connected to the upper end of R5. When an address line goes high, current flows through the associated resistor and R5 to ground, developing a voltage across R5. With the circuit shown, an 8-step waveform is present for application to the scope vertical input.

Note the relationship between the weighted outputs of the counter and the associated resistors. If the scope horizontal sweep is properly adjusted, eight discrete traces will appear on the display. As a point of interest, slightly reducing the value of R1 will produce a small gap between the upper and lower four traces so that two “nybbies” can be displayed.

Resistor R4 is connected between the output of the data selector and the D/A converter. The value of this resistor determines the amplitude of the data selector output signal. Scope sync can be taken from the system clock or from other points in the countdown chain. If the clock is very fast, a 7490/7493 or equivalent divider can be used ahead of the main counter.

Eight traces are usually the limit for observation on a 5” scope CRT. However, if your scope has sufficient writing speed and you wish to display 16 traces, substitute a 74150 (1-of-16 data selector) for the 74151. Add an 8000-ohm resistor to the new address line and the top of R5. Note that theoretical resistor values are specified in the circuit. Use nearest standard values.

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multi-channel logic

**PARTS LIST**

IC1—7493 divide-by-16 counter
IC2—74151 1-of-8 data selector
IC3—7404 hex inverter
R1—1000-ohm, 1/2-watt resistor
R2—2200-ohm, 1/2-watt resistor (see text)
R3—4700-ohm, 1/2-watt resistor (see text)
R4—50—10,000-ohm, 1/2-watt resistor
Misc.—Optional prescalers; oscilloscope connectors; color-coded 8-lead ribbon cable; grommets; suitable enclosure; miniature test clips; 14- or 16-pin IC clamp-on; machine hardware; hook-up wire; solder, etc.

**Construction.** The simple circuit can be assembled on a small perforated (or a home-made pc) board, leaving room for two or three optional ICs. The basic circuit consists of IC1, IC2, IC3 and the five resistors.

Once assembled, the board can be mounted in a small enclosure; and, if desired, a low-power 5-volt supply can be added. Since the basic circuit requires about 72 mA, the analyzer can be powered from the circuit under test.

The scope sync and vertical input connectors can be mounted anywhere on the enclosure, while the 8-lead ribbon cable (one lead for each data selector input) exits via a grommeted hole. The +5-volt, ground, and clock leads exit via their own protected hole.

The 11 leads can be terminated as desired. The prototype used miniature test clips (Radio Shack 270-372, Calec 112-916, or similar) to make the closely spaced IC pin connections. To examine a single IC, a 14- or 16-pin IC clamp-on may be used. When using such a clamp-on, the +5 volts and ground can be taken from the IC. Some form of identification must be used on each of the eight data leads.

**Use.** Connect the status analyzer to the +5 volts, ground, and clock of the circuit under test. Connect the analyzer ground and output to the scope ground and vertical input, and the sync to the scope external sync input. With operating power applied, adjust the scope sweep for eight discrete traces.

Any or all of the eight analyzer inputs can be connected to the logic under test. Adjust the sweep and sync for a stable display. Once this is done, the value of R4 can be selected for the desired signal height on the traces. To avoid confusion, make sure that the signals do not overlap. Resistor R5 can be selected for a convenient signal level input for the scope.

Although this circuit is realized with TTL chips, a resourceful experimenter could build one using CMOS logic, following the same approach.
AN APPLIANCE "OFF" REMINDER

A low-cost project provides an audible alert when an appliance indicator light goes off.

It is often useful—sometimes vital—for the user of an appliance to know if and when it ceases to operate, whether by design or due to a power failure. Usually, this is not difficult to accomplish, since most appliances are equipped with indicator lights that show when they are working. But if the appliance is not in direct view, keeping track of it can be a great annoyance.

One solution to this problem is to use an electronic "eye" that senses the radiation from the indicator light and sounds an alarm when it is interrupted. For convenience, only the sensor is required to be physically at the monitoring point; the alarm can be located where it is easily heard.

The Lights-Out Alert described here provides the answer. It is battery powered and reliable; can be built from low-cost components; and is usable with almost any sort of power-on light indicator.

Circuit Operation. As shown in Fig. 1, phototransistor Q1 and Darlington-connected Q2 form a high-gain optical-to-electrical transducer that drives a charge pump made up of Q3 and Q4 and associated components.

When no light strikes Q1, its resistance should be high enough so that Q2 is cut off. Any slight leakage from Q2 should produce less than 0.7 volt across R1—not enough to turn on Q3. Assuming that capacitor C1 has been discharged by the operation of S1, Q4 also lacks the voltage required to turn it on. Thus, all four transistors are off and current from the battery is almost nil.

When light strikes Q1, its resistance drops, depending on the illumination level, and Q2 is turned on. The voltage developed across R1 turns Q3 on provided C1 is discharged. Thus Q4 is driven deeper into cutoff. Current flows through Q3 and R2 to charge C1. When the voltage across C1 rises to within 0.7 volt of that across R1, Q3 is cut off. This condition will last as long as transistor Q1 is illuminated.

When the illumination ceases, the voltage across R1 drops. Since C1 is charged high enough to reverse-bias Q3, this transistor cuts off and turns on Q4. Discharge current from C1 now flows through R2 and Q4 to drive alarm A1.

After some time (about one minute per 10,000 microfarads of C1), C1 becomes discharged and the alarm turns off. The circuit is then ready for the next illumination period, with no current drawn from B1. Switch S1, in conjunction with R3, provides manual silencing of the alarm. This switch should not be operated during the charging cycle of C1 because this will tend to deplete the battery's charge.

Construction. The circuit consists of two physically independent sections—the light-sensitive portion and the alarm/power package, with the two interconnected by a length of flexible four-conductor cable.

The four transistors and two resistors that form the photosensor can be assembled on a small piece of perforated board or a small printed-circuit board. Make sure that the sensitive face of Q1 is in the clear so that light can pass through a hole in the case and shine on this surface. Select a low-leakage device for Q2. If phototransistor Q1 is a low-gain device (units vary with manufacturer), increase the value of R1. However, to avoid false alarms do not make the circuit too sensitive.

The board can be mounted in a small enclosure having a hole drilled so that external light can fall on the sensitive face of Q1. Another small hole can be used for the four-conductor cable. The alarm/power elements are mounted in a separate enclosure with holes near the alarm so that it can be heard.

To test the project, expose the photosensitive surface of Q1 to an ordinary household light bulb at a distance of about 18 inches. When the light source is removed, the alarm should sound for approximately one minute. Changing the value of C1 changes the alarm-on time. The alarm can be silenced by operating switch S1.

Fig. 1. Phototransistor Q1 senses when the light impinging on it goes off. The signal is then amplified to energize alarm A1.

PARTS LIST

- A1—Alarm (Sonalert SC626 or similar)
- B1—9-volt battery
- C1—10,000-μF, 10-V capacitor (see text)
- Q1—TL78 phototransistor (Radio Shack FPR-100)
- Q2—MPS3568 transistor (Radio Shack S0015)
- Q3—2N102 transistor (Radio Shack S5026)
- Q4—2N3638 transistor (Radio Shack S0029)
- R1—10,000-Ω, 1/4-W resistor
- R2—100-Ω, 1/4-W resistor
- R3—10-Ω, 1/4-W resistor
- S1—Normally open pushbutton switch
- Misc.—Length of four-conductor cable, suitable enclosures, perf board, printed-circuit board, mounting hardware, etc.
Mention timing circuits, and most people tend to think of the ubiquitous 555 IC. While the 555 is excellent for most timing applications, other devices are worthy of consideration. These are the CMOS CD4060A and SCL4060AB 14-stage ripple-carry binary counters from RCA and Solid State Scientific, respectively.

Among other advantages, the 4060-series devices can be less expensive to implement in a given application because they require less critical and less expensive resistors and capacitors. A second advantage is that 4060-series devices can deliver a number of output frequencies from the same RC components; the 555 delivers only one.

Technical Details. In a 555 timer circuit, external frequency-determining resistor and capacitor values must be selected to produce the desired oscillator frequency directly. As a result, in many cases where relatively long time constants (low frequencies) are desired, the RC product requires the use of bulky, expensive electrolytic capacitors with, often, inaccurate values and high losses.

Devices of the 4060-series use oscillator frequencies much higher than what is required at the output. The oscillator frequency goes through a 14-stage binary counter that divides it by as much as 16,384 \((2^{14})\) before it is used as the final timing frequency.

Using a much higher oscillator frequency than the 555 timer to obtain the same timing frequency the 4060 has a correspondingly smaller RC product. Hence, there is no need to use inaccurate and unstable electrolytic capacitors or humidity-sensitive, very-high-value resistors.

While the CD4060A and SCL4060AB are interchangeable in most cases, the two are different. In the CD...
4060 timer

device, the oscillator is keyed by the reset input, whereas in the SCL device, the reset operates on the dividers, leaving the oscillator in continuous operation.

Basic internal logic of the CD4060A is shown in Fig. 1. Two of the four inverter stages serve as the active elements of the internal oscillator whose output is passed through the 14-stage ripple-carry binary counter. Oscillator frequency is set by an RC network, or an external crystal oscillator can be connected to pin 9 to eliminate the need for the internal oscillator. When the internal oscillator is used, the input at pin 12 is provided to reset the counter to zero and disable the oscillator.

It is not necessary to use all 14 stages of division. As shown in Fig. 1, you can select division factors of 16, 32, 64, 128, 256, 512, 1,024, 4,096, 8,192, or 16,384, simply by picking off the output from the appropriate pin of the IC.

Timing resistance values of 4060-series devices should not be less than 10,000 ohms to avoid changes in frequency with changes in applied dc operating voltages. As can be seen in Fig. 2, the frequency/resistance function reverses at about 4500 ohms with a 5-volt supply and at 1300 ohms using 10 volts.

The frequency calculation formula for the 4060 given in manufacturer application notes is \( F = \frac{1}{(2.2R,C)} \), where \( R \) and \( C \) are the values of the timing resistor and capacitor. This formula assumes \( V_{DD} \) is 10 volts, \( C_1 \) is greater than 100 pF, \( R \) is greater than 1000 ohms, and \( R \) is less than 10 times \( R_1 \) (\( R_1 \) is the external stabilizing resistor, as shown in the inset schematic diagram in Fig. 2.) In this author’s experience, this formula is accurate only when \( R \) is greater than 50,000 ohms. With values less than 50,000 ohms, observed frequency was lower than predicted by the formula.

Data given in Fig. 2 was obtained at the pin-7 (+16) output from an SCL4060AB. With time delays of more than a few hours, it was determined that use of \( R_1 \) is not necessary.

**Practical Timer.** Shown schematically in Fig. 3 is the circuit for a practical 1-minute timer built around a 4060-series device. A 330,000-ohm resistor and 0.01-µF capacitor are doing a job that would require a 60-megohm/microfarad RC product in a 555 circuit and

![Fig. 3](https://example.com/fig3.png)

Momentary closure of START switch ST causes the set-reset flip-flop made up from two gates in a 4001 quad 2-input NAND IC to produce a high output at pin 12 of the 4060. After the timing interval (oscillator frequency) determined by \( R \) and \( C \), pin 3 of the 4060 goes low and toggles the flip-flop to stop the counter. At the same time, the output of the bottom 4001 gate, held low during the timing interval, goes high. (Since the 4001 contains four on-chip gates, the fourth gate can be paralleled with the output stage to provide more driving current for an external circuit.)

Much longer timing intervals can be obtained by cascading the pin-3 output of the 4060 with a 4020, a 14-stage counter that is similar to the 4060 but lacks the internal oscillator.

Capacitor \( C_1 \) and resistor \( R_1 \) improve the circuit’s immunity to noise and are optional.

**Summing Up.** Once you start working with 4060-series devices, you will probably think of them as often as you do the 555 for your timing applications. Their easy implementation into circuit designs and reduced demands on frequency-determining resistors and capacitors make them particularly attractive where costs must be kept down and hardware space is at a premium. And they offer a number of different output frequencies from a given RC network that gives them an important advantage over single-frequency-only timing devices.
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