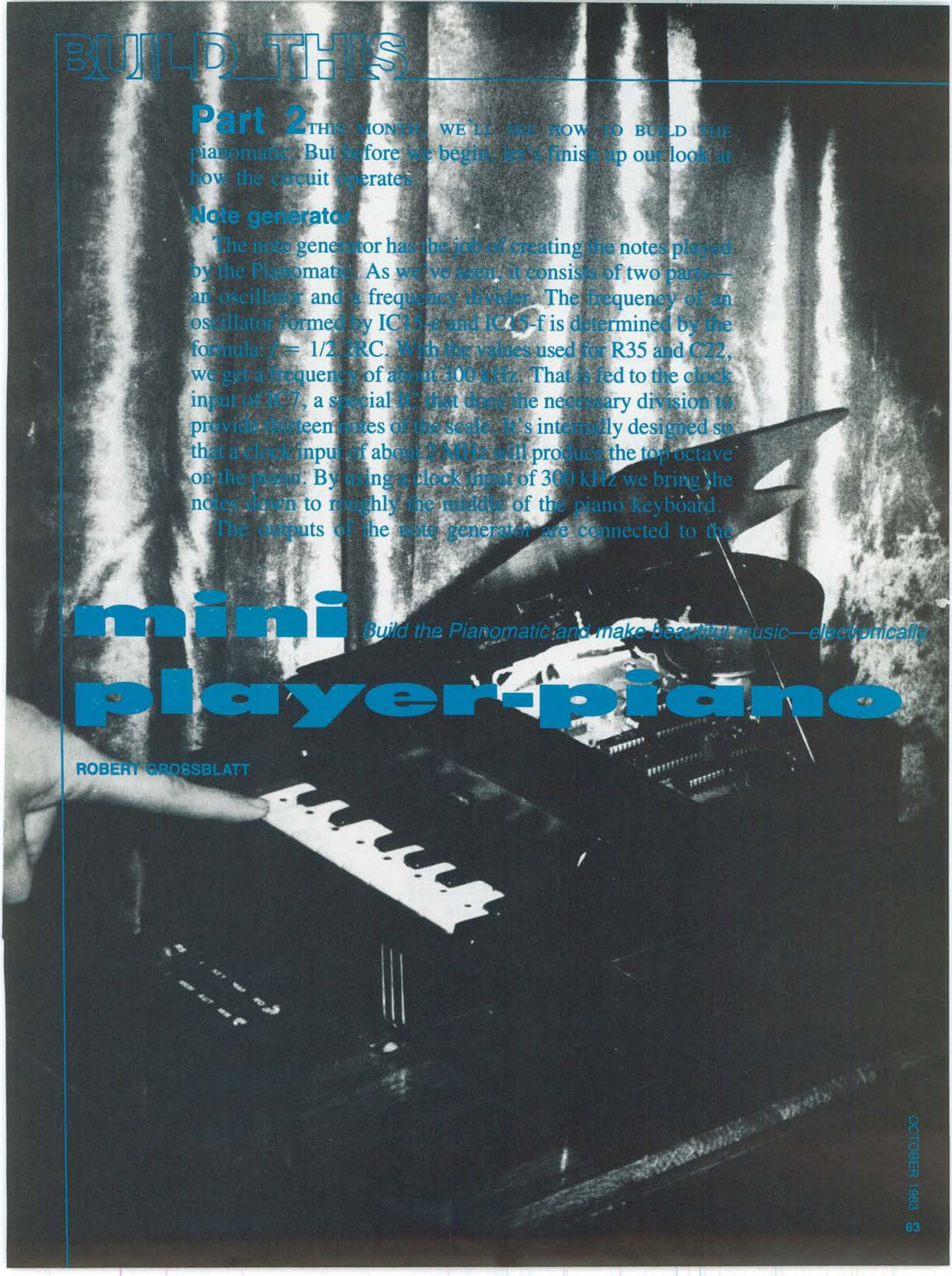
mini player-piano

Build the Pianomatic and make beautiful music—electronically.

ROBERT GROSSBLATT



Part 2 THIS MONTH, WE'LL SEE HOW TO BUILD THE pianomatic. But before we begin, let's finish up our look at how the circuit operates.

Note generator

The note generator has the job of creating the notes played by the Pianomatic. As we've seen, it consists of two parts—an oscillator and a frequency divider. The frequency of an oscillator formed by IC15-e and IC15-f is determined by the formula: $f = 1/2.2RC$. With the values used for R35 and C22, we get a frequency of about 300 kHz. That is fed to the clock input of IC7, a special IC that does the necessary division to provide thirteen notes of the scale. It's internally designed so that a clock input of about 2 MHz will produce the top octave on the piano. By using a clock input of 300 kHz we bring the notes down to roughly the middle of the piano keyboard.

The outputs of the note generator are connected to the

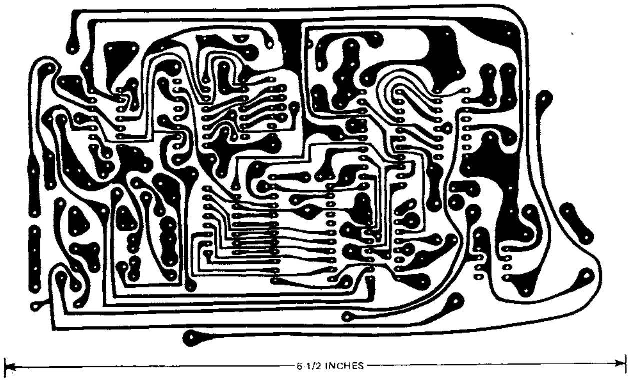


FIG. 5—TWO OF THE FIVE boards used in this project are double-sided. The foil side of one of those boards, Board 1, is shown here half-size.

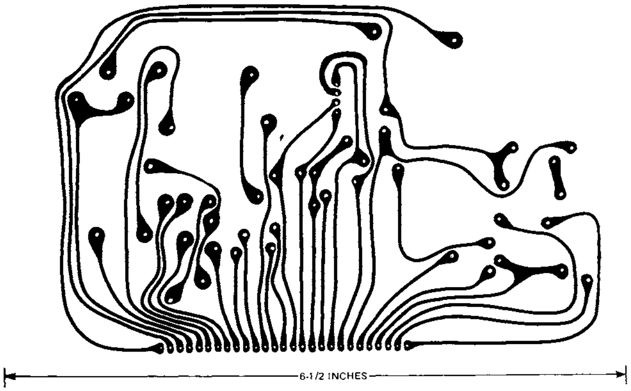


FIG. 6—THE COMPONENT SIDE OF BOARD 1. Note the pads for the male header at the bottom of the pattern. Once again this board is shown half-size.

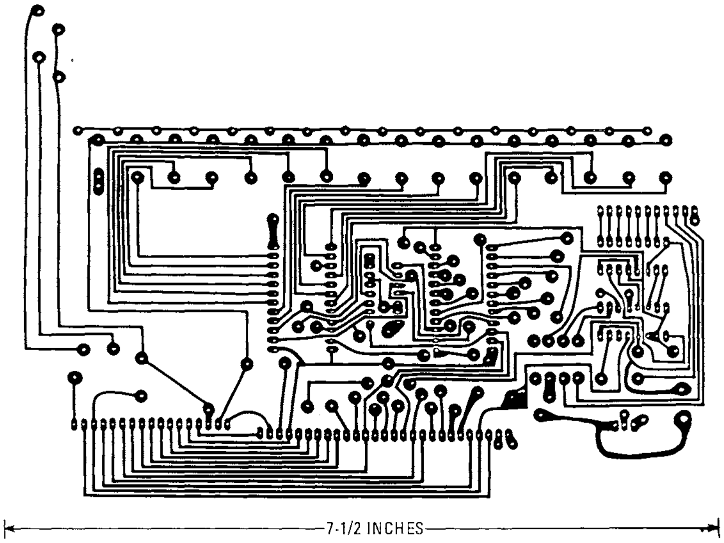


FIG. 7—THE FOIL PATTERN for Board 2. The foil side of that double-sided board is shown here half-size.

inputs of IC8, the note selector. That one-of-sixteen analog switch will output the input chosen by the binary word on the output-data bus. When the inhibit pin of the IC, pin 15, is connected to + V, it will disable the output. If we're reading a tune back from memory, we obviously want the output of IC8 turned on all the time, but if we leave it on when we're writing a tune into memory we'll run into a problem similar to the one we ran into earlier when we wanted to play the Pianomatic without writing into memory.

The problem before was caused by the fact that there was always data on the input-data bus. The problem this time is similar. There is always some data on the output-data bus, and it's not always the data we want. When we're writing a tune into memory, pressing a key will cause that note to be written into memory. Remember that before we pressed the key, there was always something stored at that location in the memory. Consequently, until we program the note we want, we'll hear whatever note was already at that memory address. Even when the memory is first put in the circuit, some sort of random data will be stored in it. If we're writing a tune on a page we've previously used, the old tune will be stored there. The way around this problem is to use the inhibit pin (pin 15) of IC8 when we're writing into memory.

Once again we use the "any-key-pressed" signal from the keyboard encoder to enable the note selector. Since we need a high to turn off IC8, we have to use the inverted version of the "any-key-pressed" signal available at the output of IC15-c. Switch S2-b connects the inhibit pin of IC8 to ground when we are reading from memory and to the inverted "any-key-pressed" signal when we are writing into memory. That means that IC8 is always enabled during a READ but, during a WRITE operation, it's only enabled when a key is pressed. Now, it's true that since this same inverted signal is also used to generate a write pulse for the memory, there will be a period of time when IC8 is enabled and the new note hasn't yet been written into memory. But let's be realistic. The write time of the memory is something like 300 nanoseconds so the old data will be present for only—to be generous—a brief period of time.

Amplifier

The output of IC8, available at pin 1, is fed to the input of IC10 through C18. That is a ½-watt integrated amplifier that can directly drive an 8-ohm speaker. The noteworthy thing here is that the gain of the amplifier is varied by the output of the tremolo clock, IC14-a. That is a low frequency oscillator running at about 6 Hz or so. The output is integrated by R31 and C21 to produce something vaguely resembling a sinewave. We're not after perfection here, but we do have to smooth it out somewhat. The reason for that is that the Pianomatic uses CMOS logic; one of the characteristics of that logic family is that oscillators using it can swing nearly the full range of the supply voltage. For the output here, the low point is pretty near ground and the high point is within shouting distance of the positive supply rail. If we connected the tremolo clock directly to the gain control pin of the amplifier, pin 8, it would turn the amplifier off every time the oscillator reached the bottom of the curve. It would be like trying to sing while someone was hitting you on the back (although there are certain kinds of music where that would be a definite plus).

Because we're using the gain-control pin of the amplifier to add tremolo, the volume of the Pianomatic is determined by the size of the capacitor, C19, that connects the output of IC10 to the speaker. The value chosen provides a comfortable level but you can change it. Raising the value will increase the volume and vice versa. Keep in mind though, IC10 is only a ½-watt amplifier and the speaker is a miniature one. If you have visions of using the Pianomatic at a rock concert, you're going to have to come up with some other output stage—you might try converting it to run off diesel power.

Memory retention

The Pianomatic will remember programmed tunes even after it's been turned off. That nonvolatility of the memory is a nice feature and understanding how it's done means that you can use the same technique in other designs. Basically we're using a backup battery to retain the memory and although the same method can probably be used with any other memory device, there are several memories that are specifically designed with that feature in mind. Those particular memories are the so-called "low-power" devices. They are generally CMOS and provide guaranteed data retention with as little as two volts applied. The rules for using them are simple since they usually have a control pin to switch the memory over to the LOW POWER mode. The Pianomatic uses three 20-milliamp-hour (mAh) nickel-cadmium button cells to provide a memory-retention voltage of 3.6. The draw is so low that 1-mAh nickel-cadmium cells could have been used if they could have been found.

Diodes D14 and D15 are used to steer the power for the memory. When the Pianomatic is turned on, D15 isolates the +V pin of the memory, D14 protects the batteries, and R16 allows the batteries to trickle charge at a rate we can figure from Ohm's law.

The operating voltage of the Pianomatic is 7.3 volts and, since D15 is a silicon diode, the drop across it will be about .65 volts. That makes the voltage at the batteries, B9-B11, 6.65 volts. Nickel-cadmium button cells should be recharged at no more than 10 percent of their rated capacity—the so-called C10 rate. In the case of our batteries that would be a recommended charging current of 20 mA/10, or 2 mA. The batteries also have a nominal voltage of 3.6 volts (1.2 volts per cell). Now that we've worked all that out, our charging resistor can be figured easily.

$V = IR$
$R = V/I$
$V = V_{system} - V_{batteries}$
$V = 6.65 - 3.6 = 3.05$ volts
$I = 2\text{mA} = .002$ amps
$R = 3.05/.002$
$R = 1525$ ohms

That's why our charging resistor, R16, is 1.5K ohms. If you use different batteries in your Pianomatic, be sure to recalculate the value of R16. Nickel-cadmium batteries have a nasty habit of blowing up

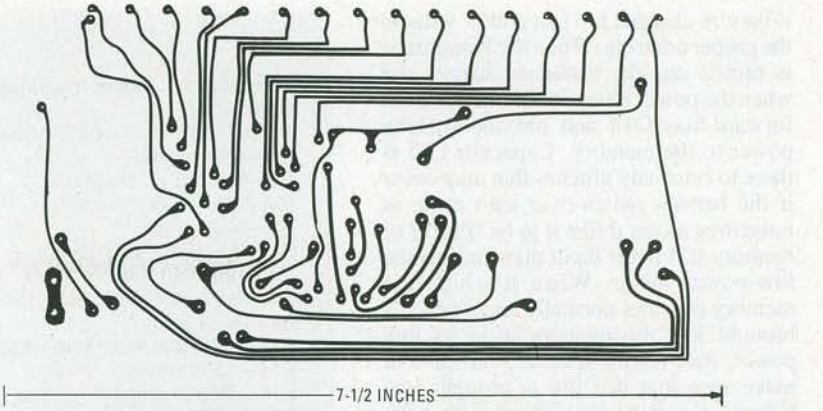


FIG. 8—FOR SIMPLICITY IN MAKING THE BOARDS, neither of the double-sided boards uses plated-through holes. The foil pattern for the component side of the second double-sided board, Board 2, is shown here. Once again, that board is shown here half-size.

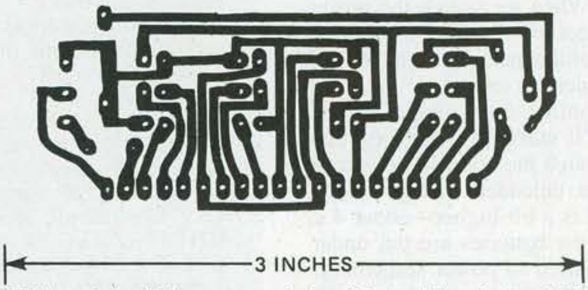


FIG. 9—MOST OF THE control switches are mounted on this small board, Board 3. Note that this foil pattern is shown full-size.

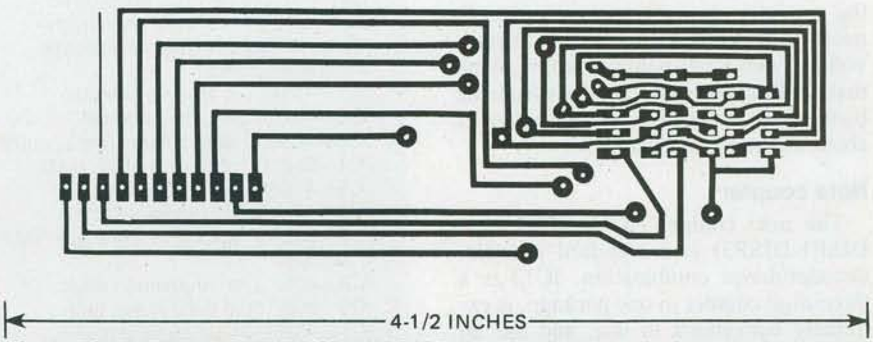


FIG. 10—FOIL PATTERN FOR THE DISPLAY BOARD. Note that there are only nine mounting holes for the LED displays. Pin 1 of each display is not used and therefore has been removed.

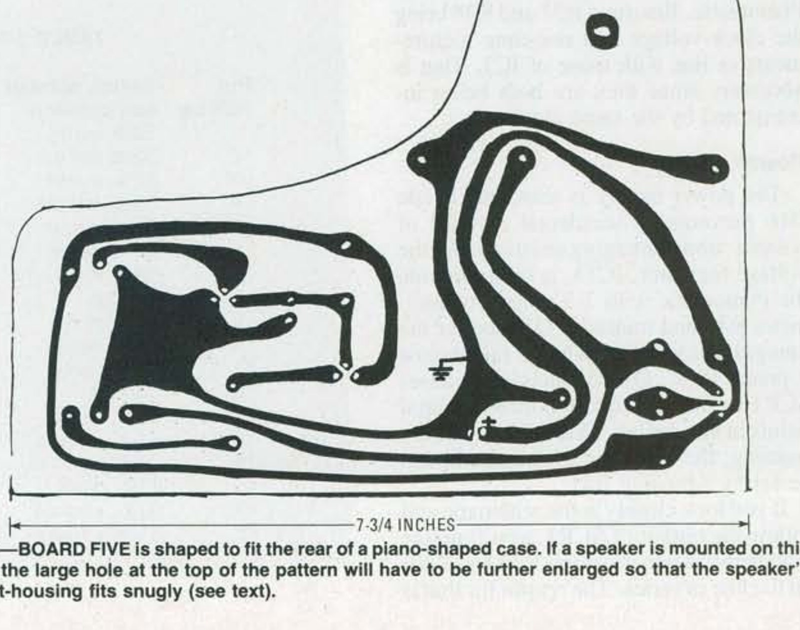


FIG. 11—BOARD FIVE is shaped to fit the rear of a piano-shaped case. If a speaker is mounted on this board, the large hole at the top of the pattern will have to be further enlarged so that the speaker's magnet-housing fits snugly (see text).

if they're charged too fast and/or without the proper controls. When the Pianomatic is turned on, the batteries charge, and when the power is turned off, the batteries forward-bias D14 and provide standby power to the memory. Capacitor C15 is there to catch any glitches that may occur if the battery switch-over isn't quite as noise-free as we'd like it to be. Pin 17 of memory IC4 is the input that controls the low-power mode. When it's high the memory operates normally and when it's brought low the memory is in its low power, data-retention mode. We have to make sure that this pin is brought low before we switch over to the standby battery supply. That is easily done by making sure that our ON/OFF switch, S8, is a SPDT type. When we switch the power off, we connect the +V line to ground. Since pin 17 of the memory is on the +V bus, our problem is solved.

If you monitor the voltage on the batteries you'll make an interesting discovery. Although the nominal voltage is 3.6 volts, the unloaded voltage of the charged cells is a bit higher—about 4.2 volts. When the batteries are put under load, that is, used to power something, you would ordinarily expect to see the voltage drop to the nominal voltage—3.6 volts. When you turn the Pianomatic off, the memory draws whatever power it needs to retain the data, but the battery voltage won't fall below 4 volts. What that is telling you is that the draw from the batteries is really low—on the order of about about 10 microamps!

Note counter

The note counter (IC11, IC12, and DISP1-DISP3) is a standard counter-decoder/driver combination. IC12 is a three-digit counter in one package, is extremely convenient to use, and has an internal multiplexer for a three digit display. The clock, reset, and blanking control lines are handled automatically by the circuitry and switching of the rest of the Pianomatic. Resistors R37 and R38 bring the clock-voltage and rise-time requirements in line with those of IC3. That is necessary since they are both being incremented by the same clock.

Power supply

The power supply is standard. Diode D16 prevents an accidental reversal of polarity from damaging anything and the voltage regulator, IC13, is set to provide the Pianomatic with 7.3 volts. Potentiometer R41 and transistor Q1 monitor the unregulated voltage. When it falls below a preset level, Q1 conducts and causes SCR1 to fire and light the three decimal points in the display. That is a low-battery warning; the trip point of the circuit can be set by adjusting R41.

If you look closely at the schematic and follow the output of SCR1, you'll notice that there are two resistors (R30 and R40) on the line in series. The reason for that is

PARTS LIST

All resistors ¼ watt, 5%, unless otherwise noted

R1, R7, R10, R17—8200 ohms
R2—6800 ohms
R3, R8, R29—1 megohm
R4, R38—10,000 ohms
R5—3000 ohms
R6, R12, R30—1000 ohms
R9—150,000 ohms
R11, R15—100,000 ohms
R13—470 ohms
R14, R19-R28, R36, R40—160 ohms
R16—1500 ohms
R18—82,000 ohms
R31—22,000 ohms
R32, R33—560,000 ohms
R34—390 ohms, ½ watt
R35—15,000 ohms
R37, R39—2200 ohms
R41—500,000 ohms, multi-turn potentiometer, PC mount

Capacitors

C1, C4, C6, C8, C9, C13, C15, C18, C20, C23, C28—0.47 μF, 35 volts, tantalum
C2—0.5 μF, ceramic disc
C3, C22—100 pF, ceramic disc
C5, C16—0.22 μF, 35 volts, tantalum
C7, C19—2.2 μF, 35 volts, tantalum
C10, C11, C14, C25, C26, C29—0.01 μF, ceramic disc
C12—47 pF, ceramic disc
C17—.001 μF, ceramic disc
C21—10 μF, 16 volts, electrolytic
C24—500 μF, 25 volts, electrolytic
C27—100 μF, 16 volts, electrolytic

Semiconductors

IC1—4514 1-of-16 data selector
IC2—4520 dual binary counter
IC3—4040 12-stage binary ripple counter
IC4—5101L-1 256 × 4 static RAM
IC5—4066 quad analog switch
IC6—4515 1-of-16 data selector
IC7—50240 top-octave generator (AMI, Mostek)
IC8—4067 1-of-16 analog switch
IC9—4082 dual 4-input AND gate
IC10—386 ½-watt audio amplifier
IC11—4511 BCD-to-7-segment-display decoder/driver
IC12—4553 3-digit counter
IC13—7805 five-volt positive regulator
IC14—4093 quad 2-input NAND Schmitt trigger
IC15—4049 hex inverter
SCR1—ECG 5400 or equivalent
Q1—2N2222A or equivalent NPN silicon transistor
D1-D3, D5-D7, D9, D11, D13, D17, D18—1N34A germanium diode
D4, D8, D10, D12—1N914 silicon diode
D14, D15—1N4001 silicon diode
D16—1N4003 silicon diode
DISP1-DISP3—FND 359, common cathode 7-segment displays with decimal point
LED1-LED13—miniature red LED
LED14-LED16—miniature green LED
S1-S3, S7—DPDT miniature switch
S4-S6—SPST normally open momentary switch
S8—SPDT miniature switch
S9-S24—SPDT miniature lever-type switch, Radio Shack 275-016, or equivalent
J1—miniature N.C. chassis-mount phone jack, Radio-Shack 274-253 or equivalent
SO1, SO2—female header strips, AP Products 929974 or equivalent
PL1-PL5—male header strips, right-angle, AP Products 929835 or equivalent
PL6—male header-strip, AP Products 929834 or equivalent
B1-B8—1.5-volt alkaline "AA" cell
B9-B11—nickle-cadmium "button" cell, 20 mAh, or larger

Miscellaneous: PC boards, IC sockets, female header-strips (AP Products 929974 or equivalent) for interconnections (see text), solder, wire, case, etc.

A set of the five PC boards, etched and drilled, but not plated through, is available from Hal-Tronix, PO Box 1101, Southgate, MI 48195. The price is $39.95. Please add $2.00 for shipping and handling. MI residents add 4% tax.

TABLE 2—BOARD 2/BOARD 3 CONNECTIONS

Pin number	Switch number and position	Connection
1	S2-b, WRITE	From Board 2, pin 17 (IC15, pin 6)
2	S2-a, center	″ ″ ″ ″ 4 (IC3, pin 11)
3	S2-b, center	″ ″ ″ ″ 5 (IC8, pin 15)
4	S3-b, MANUAL	″ ″ ″ ″ 15 (IC6, pin 1)
5	S3-a, center	″ ″ ″ ″ 2 (D3, D6 junction)
6	S3-b, center	″ ″ ″ ″ 1 (Blanking)
7	S3-a, AUTOMATIC	″ ″ ″ ″ 14 (IC15, pin 3)
8	Various	″ ″ ″ ″ 6 (Ground)
9	S7-b, PLAY	″ ″ ″ ″ 16 (IC15, pin 7)
10	S7-a, center	″ ″ ″ ″ 15 (IC6, pin 1)
11	S7-b, center	″ ″ ″ ″ 7 (IC5, pins 5, 6, 12, 13)
12	Various	″ ″ ″ ″ 13 (+V)
13	S1-a, center	″ ″ ″ ″ 12 (IC3, pin 4)
14	S1-a, 2 TUNES	″ ″ ″ ″ 10 (IC4,pin 7)
15	S1-b, 2 TUNES	″ ″ ″ ″ 9 (IC2, pin 12)
16	S1-b, center	″ ″ ″ ″ 11 (R-12)
17	S1-b, 4 TUNES	″ ″ ″ ″ 8 (IC2, pin 13)
18	S1-a, 4 TUNES	″ ″ ″ ″ 3 (D18)

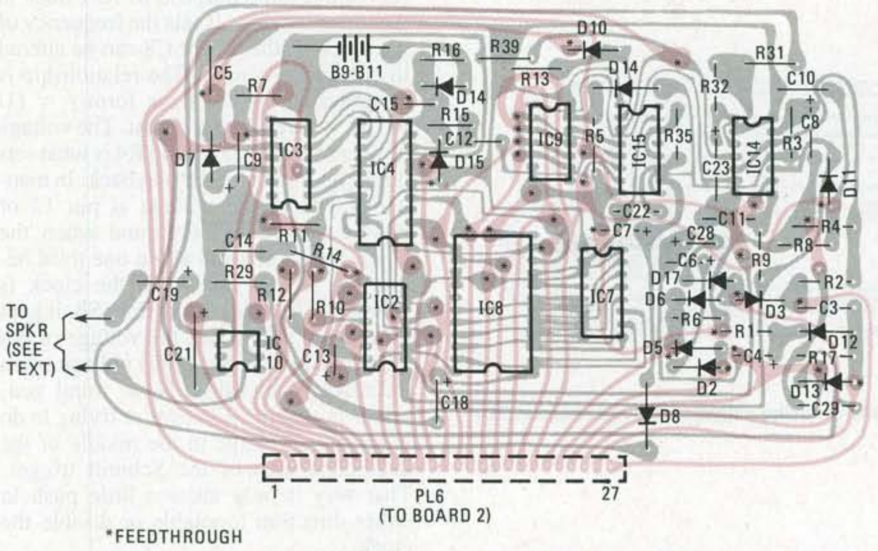


FIG. 12—PARTS-PLACEMENT DIAGRAM for Board 1. Note that female header, PL6, mounts on the foil side of the board.

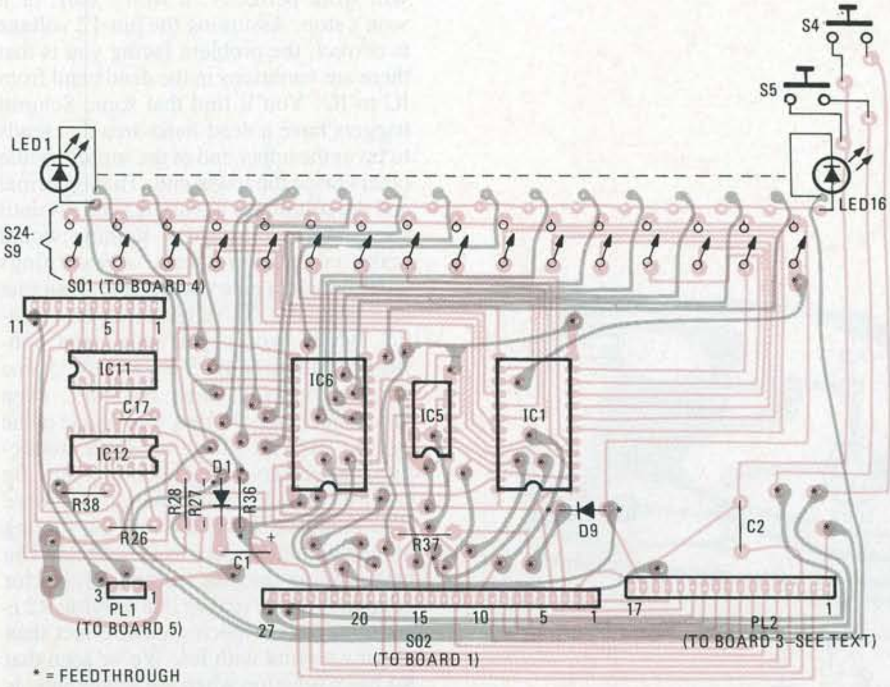


FIG. 13—AS SHOWN HERE, the cathode connections for LED1–LED16 are located on the foil side of Board 2.

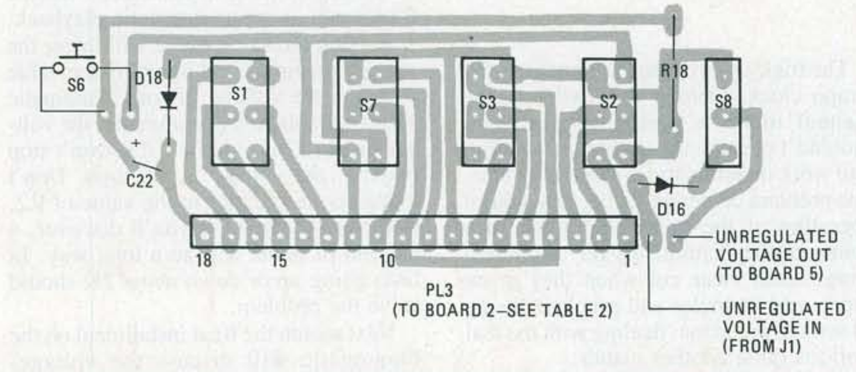


FIG. 14—THIS TINY, single-sided, board can be mounted anywhere that is convenient. In the prototype it was mounted in a "piano bench."

that they are on two separate boards. Resistor R40 is on the display board because locating it there allows us to test the board all by itself.

Keyboard display

The last part of the Pianomatic that we'll look at is the keyboard display, controlled by IC6, a one-of-sixteen data selector similar to the keyboard selector, IC1. The output-data bus is monitored by IC6; that IC puts a low at the pin selected by the word on the bus. Those outputs are used to turn on small LED's buried in the piano keys. The inhibit input is connected to the center pole of switch S7-b, half of the PLAY/MEMORY switch. That means that the LED's will be turned on only when the memory is enabled. Since only one LED will be on at a time, we only need a single current-limiting resistor, R36.

Construction

Now that we understand how the Pianomatic works, we can put it together. You could use perfboard and wire wrap the whole thing—after all, the pyramids were built thousands of years ago with primitive tools and they've lasted—but the use of printed-circuit boards is strongly suggested. The PC-board patterns for the device are shown in Figs. 5–11; the parts-placement diagrams are shown in Figs. 12–16. If those are used, the project becomes neater and cleaner.

There's nothing particularly complicated about the construction of the Pianomatic. The circuit has been designed to fit on five separate boards. The interconnection diagram for the boards is shown in Fig. 17 (which appears next month). The interconnection between boards 2 and 3 is a little complicated, so to simplify things it's been listed in Table 2.

There is one small complication with the boards: two of them—boards 1 and 2—are, unfortunately, double sided. Don't forget to solder small pieces of wire to both sides of the double-sided boards as feedthroughs. All feedthroughs are indicated by asterisks on the appropriate parts-placement diagrams. Where possible, the feedthroughs were done on the legs of the components, but there are some that had to stand by themselves.

A few important points: First, note that the pads for the LED's are on the front of board 2 in between the pads for keyboard switches S9-S24 (see Fig. 13). Notice that the cathode pads are on the component side of the board and the anode pads are on the foil side. Also, the cathode of LED16 is used as a feedthrough between the two sides of the board; be sure to solder it on both sides of the board. Finally, watch the polarity of electrolytics and IC's and above all, use IC sockets.

There are several options available to you in building the Pianomatic and one really tricky thing to watch out for. You can change the speed of the tremolo by

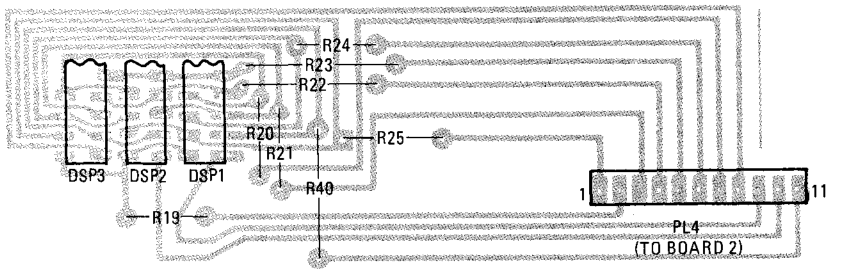


FIG. 15—THE DISPLAY BOARD mounts directly on Board 1 using a right-angled male header, PL4.

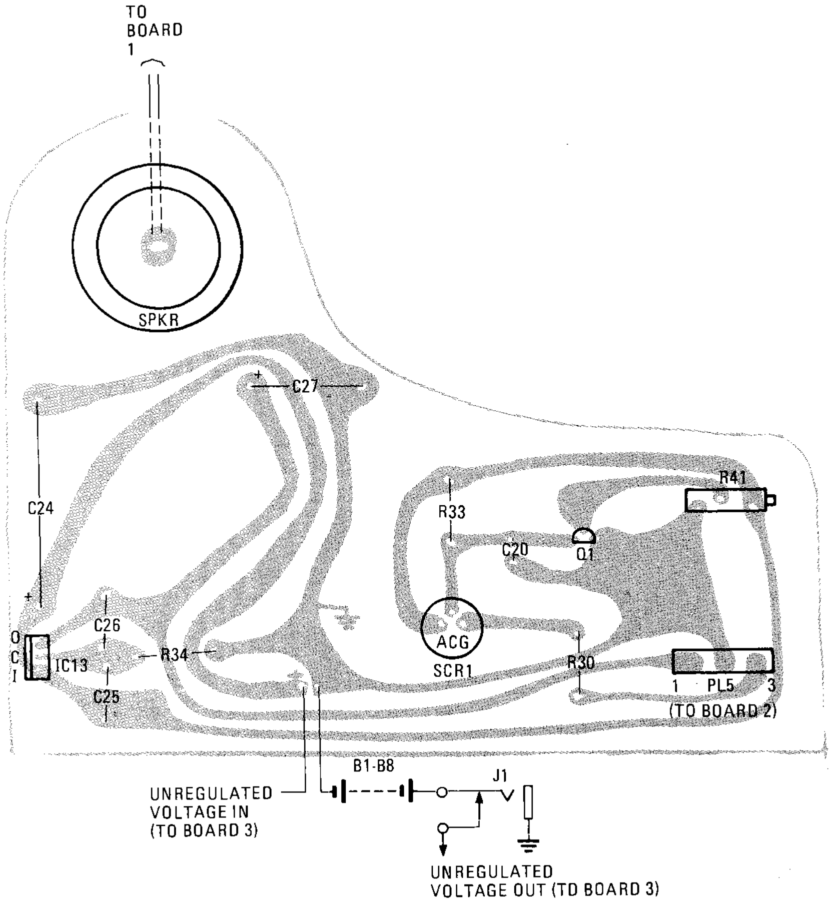


FIG. 16—MOST OF THE POWER-SUPPLY COMPONENTS mount on Board 5. Batteries B1–B8 and jack J1 can be mounted anywhere that is convenient. In the prototype they were mounted in the wood base.

adjusting the value of R32. Raising the value will slow it down and lowering the value will, logically enough, speed it up. The pitch of the Pianomatic can be changed by adjusting the parameters of the oscillator made from IC15-e and IC15-f. Just plug the values of R35 and C22 into the formula $f = 1/2.2RC$ and you'll be OK. Remember, though, IC7 does a good deal of division internally. The lowest note available from IC7 is the input frequency divided by 478, so bear that in mind when you start substituting values.

The tricky part of the Pianomatic is the tempo clock. Getting it to work in the manual mode is straightforward and shouldn't present any problems—getting it to work in automatic is something else. The problem comes about because you're operating at the upper and lower trip points of the Schmitt trigger. Although things seem clear cut when they're on paper, and formulas and graphs indicate all sorts of precision, dealing with the real world is quite another matter.

The important parameters in the tempo clock are R2, R3, and R4. Resistor R3 serves the same purpose as R31 does in the tremolo clock. It sets the frequency of the clock. Either R3 or C8 can be altered to change the tempo. The relationship is complicated but is of the form $f = (1/RC)K$, where K is a constant. The voltage divider made up of R2 and R4 is what sets things up for automatic playback. In manual playback, the voltage at pin 12 of IC14-d should be at ground when the clock is disabled and about one third below the supply rail when the clock is enabled (when the start switch, S4, is kept closed). In automatic, the voltage of pin 12 should be half the supply voltage when the clock is disabled. Now, mind you, that is in theory. What we're trying to do is keep the voltage in the middle of the dead-band area of the Schmitt trigger. That way it only takes a little push in either direction to enable or disable the clock.

When you put your Pianomatic in automatic, one of three things will happen—it will work perfectly, it won't start, or it won't stop. Assuming the pin-12 voltage is correct, the problem facing you is that there are variations in the dead band from IC to IC. You'll find that some Schmitt triggers have a dead-band area that tends to favor the upper end of the supply, while others favor the lower end. That is normal and the solution is to vary R2 and R4 until the circuit works. Now, nothing would make us happier (well, a *few* things would) than to give you numbers, but that is impossible. We've taken our Pianomatic, which works perfectly, and substituted different 4093's for IC14. Some would work and some wouldn't, even though no other changes were made in the circuit. Even IC's from the same production run will have different trip points. Be comforted by knowing that any of those IC's could be made to work by fooling around with the values of R2 and R4. The best way to find the correct values for your circuit is to realize that varying R2 is going to have a much greater effect than playing around with R4. We've seen that R4 has a function when the Pianomatic is in manual as well as automatic playback—it pulls pin 12 low to stop the clock. On the other hand, R2 has no purpose in life other than keeping pin 12 in the middle of the dead-band area when the Pianomatic is set to automatic playback.

Raising the value of R2 will lower the voltage on pin 12 and lowering the value will raise the voltage. If your Pianomatic won't start playing in automatic, the voltage on pin 12 is too low—if it won't stop playing, the voltage is too high. Don't make heroic changes in the value of R2, however, because, as you'll discover, a handful of ohms will go a long way. In fact, going up or down about 2K should solve the problem.

Next month the final installment on the Pianomatic will discuss the voltage-regulator circuit, operation, troubleshooting, and calibration. **R-E**