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Radio-Electronics

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ONE OF THE FIELDS THAT HAS BENEFITED MOST FROM THE revolution in digital electronics is electronic music. That's because the relationships between notes can be expressed mathematically, making music the perfect candidate for digital logic. These days, the use of electronically generated music is limited only by imagination and the demands of the marketplace, and common applications include everything from doorbells to watches.

Anyone who has dabbled in electronics knows that there are an infinite number of sounds that can be produced electronically. Unfortunately, the majority of them are the squeals and yowls of wayward circuitry. Producing music electronically means being able to control not only what sounds you produce, but the order in which you produce them. This project, the Pianomatic, is a good beginning for anyone who is interested in designing control circuitry for electronically generated music. The unit has a keyboard that will play a full

mini player-piano

Build the Pianomatic and make beautiful music—electronically.

ROBERT GROSSBLATT

octave, and a memory section that will remember as many as four tunes even when it is turned off. The notes are entered into the memory from the keyboard and either a half or full rest between notes can be programmed.

Although a full-blown electronic piano has a much wider range of notes and features, the principles used by the Pianomatic are exactly the same. Once you understand how it works, we'll show you how it can be expanded to provide as many features as you want. The keyboard can be extended to cover a range of several octaves and much more attention can focussed on refining the sound. But we're getting ahead of ourselves. Let's first look at Fig. 1, a block diagram of the device. Then, we'll examine each section in detail.

An overview

The keyboard encoder translates the pressing of each key into a unique binary four-bit word. At the same time, it generates an ''any key pressed'' signal that the Pianomatic uses to increment its counters and to control several of its automatic functions. If we're writing a tune into memory, that signal is also used to generate the ''write'' pulse.

The memory of the Pianomatic can be organized into either two or four pages at the throw of a switch. That means you have the choice of programming either two longer tunes or four shorter ones. Addressing is controlled by the note counter and the tune selector.

What we mean by ''paging'' is that some of the address lines are used to select which part of the memory is going to be accessed. That technique of memory management is frequently used whenever lots of information is stored in system memory—the more extensive the memory, the more useful the technique. Let's suppose, for example, that you had a system that used an address bus that was ten bits wide. That would mean you could address 1K words of memory (2^{10} = 1024 = 1K). (A word is a group of bits that are considered as a whole. In a personal computer, for example, a word might be 8 or 16 bits long, depending on the machine.) If you wanted to organize that memory into two pages, you would have to break the memory down and think of it as being made of two parts, each being a page that was 512 words long. The most significant address line would then be used to select the page of memory you wanted to access. That system is shown in Fig. 2. In that example, address line A9 is switched between +V and ground, and is used to select the page of memory that will be accessed. Address lines A0 to A8 are used to select a memory location on that page. Once the memory location is selected, the data is stored.

The data bus of the Pianomatic is four bits wide, so we can select 16 separate four bit words (2^4 = 16). Thirteen of those are used for individual note selection, one is for a full rest, and the remaining two words are decoded by the tempo clock control to, logically enough, control the tempo clock during playback from memory. One of the two words causes the tempo clock to speed up and create a half rest and the other disables the clock at the end of a tune.

The tempo clock increments both the note counter and the display counter. The former addresses the memory and the latter controls a three-digit display that allows you to easily keep track of which note is being played.

The note generator is composed of two parts—an oscillator, and a top-octave generator, shown in Fig. 3; that IC performs the frequency division necessary to produce thirteen notes of the equally tempered scale. Each note is related to the others by some multiple of $\sqrt[12]{2}$. In other words, since the frequency of a middle A is 440 Hz, an A-sharp would be 440 × $\sqrt[12]{2}$, or about 466 Hz.

The outputs of the top-octave generator are connected to the note selector—a one-of-sixteen analog switch that is controlled by the output data bus. Once the note is selected, it is passed on to the amplifier and speaker; the sound is given a bit of coloring by having the tremolo clock rapidly vary the gain of the amplifier.

Each key on the keyboard has a small LED in it, and whenever a note is played the corresponding LED lights up. That makes it easy to keep track of which note is being played and provides a bit of visual appeal when you are playing a tune back from memory.

As you can see by now, the organization and operation of the Pianomatic are logical and straightforward. When you're writing a tune into memory, a key is pressed and the corresponding word is latched onto the data bus. The ''any-key-pressed'' signal generates a write pulse

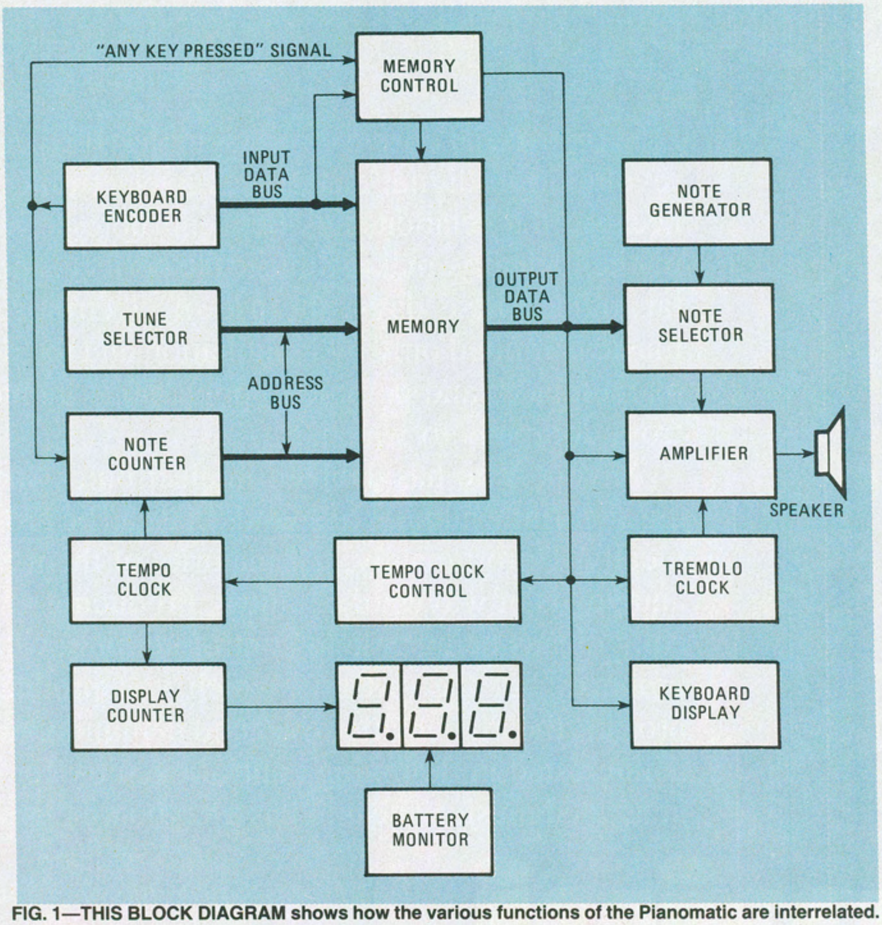


FIG. 1—THIS BLOCK DIAGRAM shows how the various functions of the Pianomatic are interrelated.

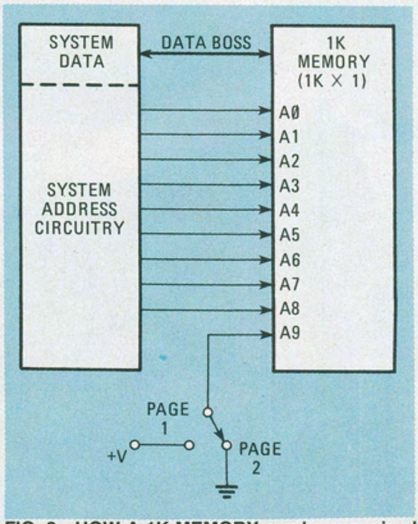


FIG. 2—HOW A 1K MEMORY can be organized into two pages, each 512 words long. In this simplified circuit, the most-significant-address line is switched to choose between two pages of memory.

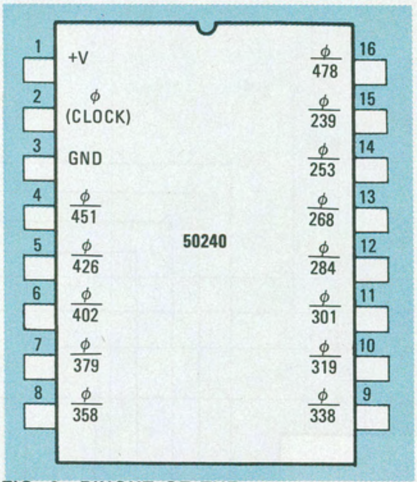


FIG. 3—PINOUT OF THE 50240 top-octave generator. Although the specifications for that IC call for a supply voltage of between 11 and 16 volts, the device will operate reliably at the Pianomatic's 7.3 volts.

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.

and the note is written into memory. It appears on the output data bus and the note selector connects the chosen note to the amplifier. When you release the key, the keyboard encoder starts scanning again and the note counter is automatically incremented by one. In playback, the note counter is advanced by the tempo clock and addresses the memory. The stored binary information is sequentially put on the output data bus and the note selector connects the note to the amplifier.

Let's next look at each of the sections in detail and see how they work. The schematic diagram for the Pianomatic is shown in Fig. 4. You'll probably want to refer to it now and then as we discuss the various sections.

Keyboard encoder

The keyboard encoder is of the scanning type and is made up of a clock (IC14-c), a binary counter (IC2-a), and a one-of-sixteen data selector (IC1). The keyboard itself is a series of normally-open, momentary SPST switches connected to the outputs of the data selector. As long as no key is pressed, the clock is enabled and causes the binary counter to count at about 1.5 kHz. That makes the outputs of the data selector go high in sequence. When a switch is closed, nothing happens immediately because the unselected outputs of the data selector, IC1, are low. When the binary counter causes the chosen output to go high, D11 is forward biased and disables the clock input of the counter. The same signal is inverted by IC15-c and disables the clock. The effect of all that activity is to stop the scanning dead in its tracks and latch a binary word on the input data bus corresponding to whichever switch was closed. Diode D9 is also forward biased and increments both IC3, a 4040 binary ripple counter that serves as our note counter, and IC12, a 4553 three-digit counter that is our display counter. The inverted version of the "any-key-pressed" signal, available at the output of IC15-c and through C12, is used to generate the "write" pulse for the RAM IC, IC4. Since keyboard switches S9–S24 are mechanical, R8 and C10 are used to debounce them.

Pin 23 of IC1 is the inhibit input of that device and it gives us a simple way of disabling the entire keyboard. If we make that pin positive, we force all the outputs to remain at ground, so closing a switch on the keyboard will have no effect on the rest of the keyboard encoder. That's handy because there are times when we don't need or want the keyboard to be working. If we're playing a tune back from memory, for example, there's no need for the keyboard to be operating. If it were, and you pressed a key during playback, a write pulse would be generated causing a glitch in the memory.

Memory

As we mentioned before, the memory of the Pianomatic can be organized into either two or four pages. The addressing of the memory is done by the note counter, IC3, and the tune selector, IC2-b. Since the memory, IC4, is a 1K memory organized into 256 words by 4 bits, it has eight address lines, ($2^8 = 256$) labelled A0 through A7 (pins 4, 3, 2, 1, 21, 5, 7, and 6 respectively). The six least-significant address lines are connected directly to the corresponding outputs of the note counter. One of the two most significant address lines, A6, is connected to the least significant ("A") output of the tune selector (pin 11 of IC2-b). The ability to select either two or four pages of memory is made possible by how we handle address line A7. If we want to organize the memory into four pages, the seventh output of the note counter, (pin 4 of IC3), is

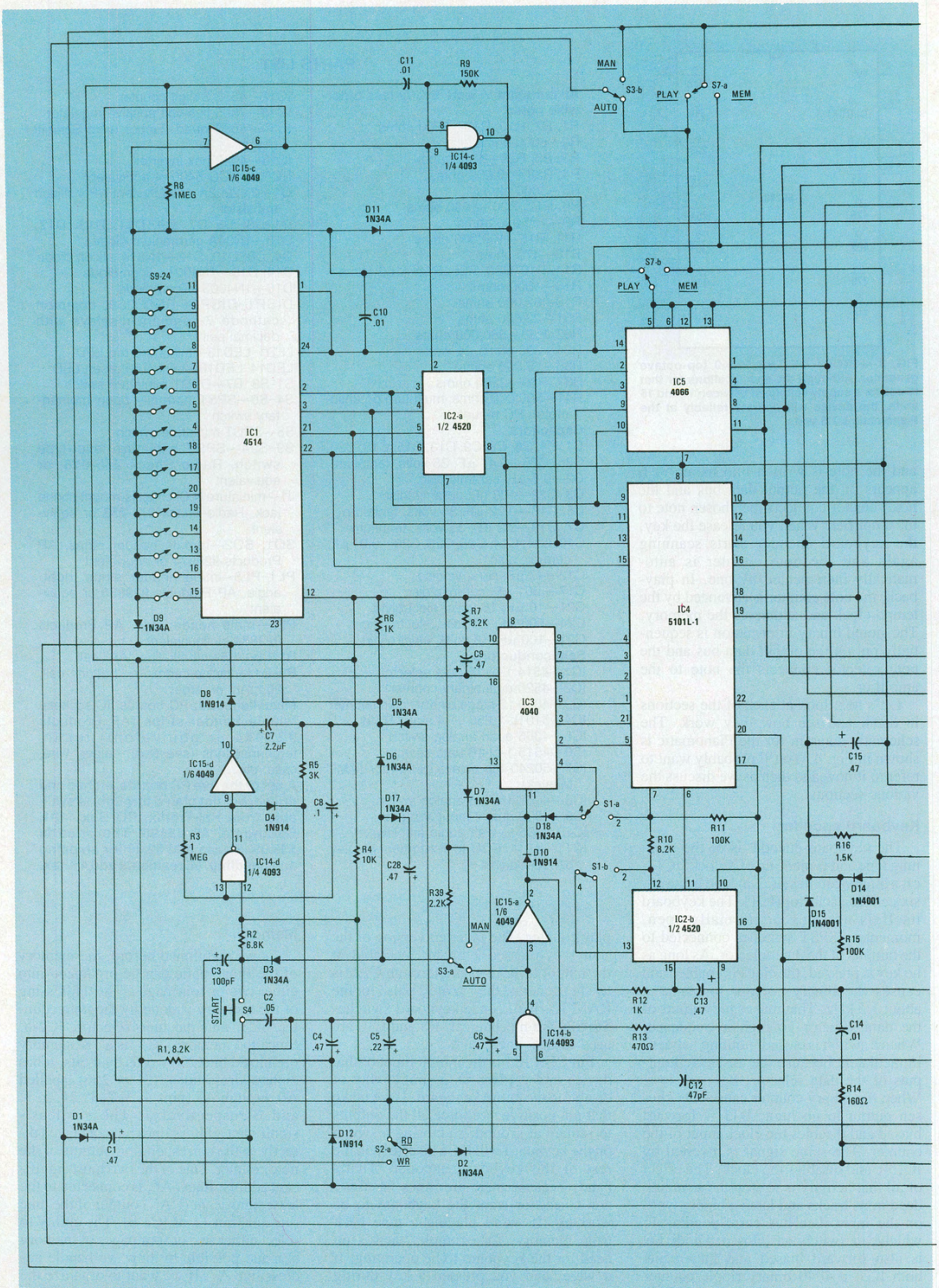
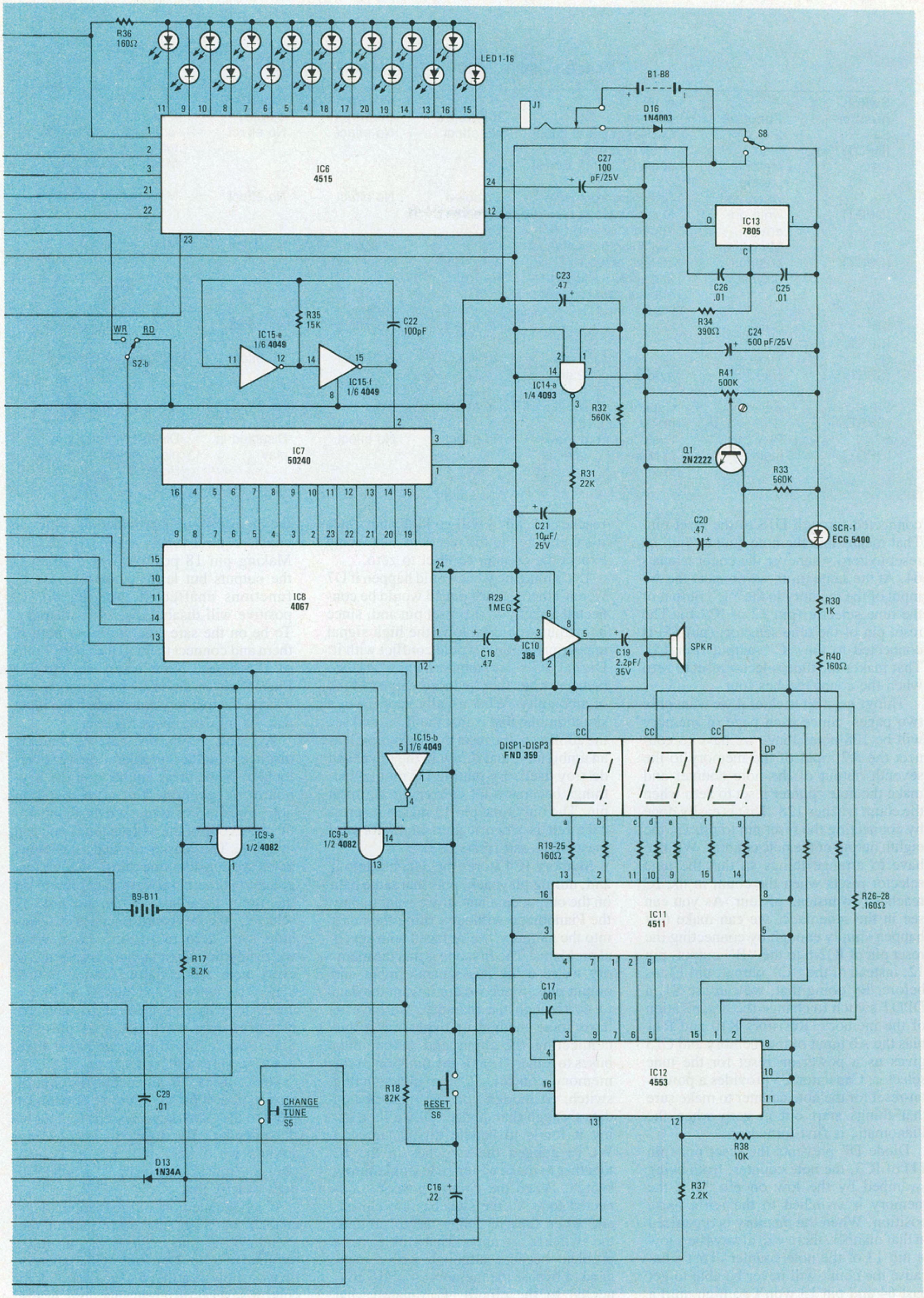


FIG. 4—SCHEMATIC DIAGRAM OF THE PIANOMATIC. This circuit can store either two long tunes or four shorter ones.



R36 160Ω
LED 1-16
IC6 4515
B1-B8
J1
D16 1N4003
S8
C27 100 pF/25V
IC13 7805
C26 .01
C25 .01
R34 390Ω
C24 500 pF/25V
R41 500K
Q1 2N2222
R33 560K
SCR-1 ECG 5400
C23 .47
R35 15K
C22 100pF
IC15-e 1/6 4049
IC15-f 1/6 4049
WR
RD
S2-b
IC14-a 1/4 4093
R32 560K
IC7 50240
R31 22K
C21 10µF/25V
C20 .47
IC8 4067
R29 1MEG
C18 .47
IC10 386
C19 2.2pF/35V
SPKR
R30 1K
R40 160Ω
IC15-b 1/6 4049
DISP1-DISP3 FND 359
CC
DP
IC9-a 1/2 4082
IC9-b 1/2 4082
R19-25 160Ω
R26-28 160Ω
B9-B11
IC11 4511
R17 8.2K
C17 .001
IC12 4553
C29 .01
CHANGE TUNE S5
R18 82K
RESET S6
R38 10K
D13 1N34A
C16 .22
R37 2.2K

TABLE 1—SWITCHING OF THE PIANOMATIC

Switch number	Function	Note counter	Keyboard	Note counter display	Keyboard display	Misc.
S1 (DPDT)	2 or 4 tune memory paging	Causes reset at count of 64 (4 tunes) or count of 128 (2 tunes).	No effect	No effect	No effect	Changes resetting of tune selector, IC2-b. Mounted on Board 3.
S2 (DPDT)	Read and write operation	Switching from write to read causes reset through D2 and C6.	Disabled in read via D5.	No effect	No effect	Mounted on Board 3.
S3 (DPDT)	Manual or automatic playback	Switching from manual causes reset via D17 and C28. Switching to manual causes reset via D1 and C1.	Disabled in automatic via D6.	Blanked in automatic	No effect	Mounted on Board 3.
S4 (SPST)	Start	No effect	No effect	No effect	No effect	Mounted on Board 2.
S5 (SPST)	Tune select	Causes reset in all modes via D12 and C4.	No effect	No effect	No effect	Mounted on Board 2.
S6 (SPST)	Reset	Causes reset in all modes via C16.	No effect	No effect	No effect	Mounted on Board 3.
S7 (DPDT)	Play or memory	Switching from Play to Memory causes a reset via C2.	No effect	No effect	Disabled in play	Disables memory in play. Mounted on Board 3.

connected through D18 to the reset pin. That means that the note counter will be reset to zero whenever the count reaches 64. At the same time, we connect the A7 input of the memory to the "B" output of the tune selector (pin 12 of IC2-b). The reset pin of the tune selector, (pin 15) is connected to the "C" output (pin 13). That makes the tune selector reset to zero when the count reaches four.

Things get a bit trickier if we want only two pages. Since each page of memory will be 128 notes long, we have to connect the A7 input of the memory to the seventh output of the note counter and make the note counter reset to zero when the count reaches 128. That is easily done by connecting the reset pin to pin 13, the eighth output of the note counter. We also have to arrange things so that the tune selector resets when the count in the IC reaches two instead of four. As you can see in the schematic, we can make that happen simply enough by connecting the reset pin of IC2-b to the "B" output, pin 12, instead of the "C" output, pin 13, as before. By doing that, we can use S1, a DPDT switch to change the organization of the memory. Resistors R10 and R11 bias the A6 input of the memory and C13 gives us a power-on reset for the tune selector. Capacitor C5 provides a power-on-reset for the note counter to make sure that things start out at zero when the Pianomatic is first turned on.

Diode D7 prevents the reset pin (pin 11) of IC3, the note counter, from being swamped by the low on pin 13 if the memory is switched to the FOUR PAGE position. When the memory is organized in that manner, there will always be a low at pin 13 of the note counter. That's because the count will never be able to get past 64 and pin 13 won't go high until a count of 128 is reached. When the count reaches 64, pin 4 will go high and, since it's connected to the reset bus, we would expect the counter to reset to zero.

Let's imagine what would happen if D7 weren't there. Since pin 13 would be connected directly to the reset pin and, since its output would be low, the high signal appearing on pin 4 would conflict with it. Digital IC's are tempermental and go bananas when they're faced with any kind of ambiguity. What usually happens in a situation like that is that the IC would see the conflict at the reset pin, recognize it as an ambiguity, and throw in the towel and destroy itself. By putting D7 on the line, things become a lot clearer for the reset pin. The only time pin 13 makes its presence felt is when it goes high, forward biases D7, and resets IC3.

Memory IC4 stores the data put into it and, during playback, puts that same data on the output data bus. If we want to play the Pianomatic without writing the notes into the memory, we're faced with several problems. The first one is that the memory we're using has separate input and output pins. Since we don't want the data to go through the memory, we have to have some method of bypassing it and connecting the input and output data buses together. That is the function of the memory control, IC5, a quad analog switch. (Although you can route analog data through that device, all we'll be using it for is to handle digital signals.) We've ganged the switches in the IC together to make a four-pole single-throw switch. When the control pins are connected to +V, the switches are closed, and when they're connected to ground, the switches are open. That still leaves a problem because although we've managed to bypass the memory, it's still connected to the circuit. Fortunately that problem was forseen by the designer of the memory—he's provided us with two enable-control inputs at pins 18 and 19. Making pin 18 positive will disconnect the outputs but leave the rest of the IC functions unaffected. Making pin 19 positive will disable the entire memory. To be on the safe side we'll use both of them and connect them to the control pins of the 4066. Now when we put the Pianomatic in the PLAY ONLY mode, we disable the memory and connect the input and output data buses together.

As soon as we do that, we quickly discover another problem we've overlooked. If we press any key on the keyboard we generate the corresponding note, but if no key is pressed the Pianomatic makes one of the worst sounds you can imagine. The reason for that is obvious when we consider one thing—we've forgotten that there's always data present on the input data bus. When no note is selected, the keyboard encoder is scanning from zero to fifteen. Thus, what we're hearing when no note is selected is every note sequentially selected at 1.5 kHz. The way around that is to find a means to enable the 4066 (and disable the memory) only when a key is pressed. Since the keyboard encoder has a high "any-key-pressed" output, our answer is evident. Instead of connecting the control pins of the 4066 to +V, we'll connect them to the "any-key-pressed" output of the encoder. By doing that, the only sounds we'll hear will be, to coin a phrase, "music to our ears." Switch S7-b does exactly that.

When the memory of the Pianomatic is enabled by S7-b, the other half of the switch, S7-a, puts +V on the MANUAL terminal of S3-b. One look at the schematic will show you that we're using that to control several different functions of the

continued on page 81

MINI PLAYER-PIANO

continued from page 48

Pianomatic—the enabling of the keyboard display, IC6, the display counter, IC11, the TUNE SELECTOR switch, S5, and finally, the START switch, S4. Let's take a look at the last of those first and see how the Pianomatic operates when it plays a tune back from memory.

Playback

The circuit consisting of IC14-d, R3, and C-8 is a gated oscillator. By "gated oscillator" we mean that a high logic level turns it on, and a low turns it off. The Pianomatic has two modes of playback—AUTOMATIC and MANUAL. In MANUAL, switch S3-b puts +V on one side of the START switch, S4. The other side of the START switch is connected through resistor R2 to the control pin, pin 12, of the tempo clock, IC14-d. As long as the START switch is kept closed, the tempo clock will operate, be inverted by IC15-d, and, through D18, increment the note counter, IC3. That will sequentially address the memory in binary form, causing the tune to be played. When S4 is open, resistor R2 pulls pin 12 (IC14-d) low and the tempo clock stops.

The AUTOMATIC PLAYBACK mode is one of the nicest features of the Pianomatic. When the START switch, S4, is pressed, the Pianomatic reads out the data on the selected page of memory and stops. The interesting point of that is that it doesn't stop at the end of the page; it stops wherever you've programmed it to stop. We accomplish that piece of magical business by some creative gating and selective decoding. Let's now see exactly how that is done.

As we've seen before, when we're playing back from memory in MANUAL, S3-b puts +V on the C2 side of S4. As long as S4 is kept closed, IC14-d is enabled and the tune plays. In order to have the tune continue playing after S4 is released, we need some way of keeping IC14-d enabled. We do that by using the *b* half of the MANUAL/AUTOMATIC switch, S3-a. In the MANUAL position, the switch is connected to ground, but in the AUTOMATIC position it's connected to the output of IC14-b. The operation of that gate is the key to the automatic-playback feature of the Pianomatic.

The output of IC14-b is controlled by the voltages on pin 12 of IC14-d, the enabling pin of the tempo clock, and the output of AND gate IC9-a. That gate monitors the output-data bus and is set to decode a binary 15 (1111). In other words, the output of IC9-a will be low unless a binary 15 appears on the output-data bus. Let's assume that S3 is set on AUTOMATIC, the START switch, S4 hasn't been pressed, and that any number but 15 is on the output-data bus. Since the output of IC9-a is a low and pin 12 of IC14-d is low, the output of IC14-b will be high. That will bias D6 and disable the keyboard by making pin 23 of IC1 high. It will also forward bias D3 and slightly raise the voltage at pin 12 of IC14-d.

When S4 is pressed, IC14-d is enabled just as it was in MANUAL playback. In AUTOMATIC, however, releasing the switch won't disable the clock because the output of IC14-b remains high and doesn't let R2 pull the enabling pin low enough to stop the clock. Remember that IC14 is a Schmitt trigger, so there is a certain amount of hysteresis inherent in the device. Because of that, it takes more than a 50% voltage swing to make the gate change state. By choosing appropriate values for R2 and R4, we can take advantage of the "dead band" area of the Schmitt trigger. As long as we don't allow pin 12 of IC14 to drop below the trip voltage point, it will remain high and the clock will remain enabled. In manual playback, R2 was able to pull pin 12 low, but in AUTOMATIC, the high output of IC14-b raises the voltage just enough to prevent that from happening.

Even though pin 12 remains high, the output of IC14-b doesn't change because IC9-a is still presenting a low to the other input leg of the gate at pin 6. Let's suppose that a binary 15 appears on the output-data bus. That will be detected and decoded by IC9-a, and the output state of that IC will change to a high. Since a high signal is being presented to both legs of IC14-b, its output will change and it will go low. That will put a low at pin 12 of IC14-d, lower the voltage past the trip point, and disable the clock. Thus, when we are writing a tune into memory the last thing to put in the program is a binary 15. By doing that, playback will stop at that point in memory. A low at the output of IC14-b will be inverted by IC15-a and present a high to the reset pins of the note counter IC3. When a "stop" signal is present on the output data bus, therefore, not only will the Pianomatic stop playing, but the device will also reset itself to zero again.

In order to make the Pianomatic easier to use, there are several things that will make the note counter, IC3 reset to zero. A glance at the schematic will show you that there is a whole bunch of "Mickey Mouse logic" (M^2L) tied to the reset pin of IC3. That takes the form of diode-capacitor combinations that cause various switching of the Pianomatic's controls to put a positive pulse on the reset bus. Rather than go through all of it here, it's much easier to put it in table form; we've done that in Table 1. That table shows the actions and effects of the switches in the Pianomatic. In general, the only action that won't reset IC3 is going from READ to WRITE. That was done to make it easier to correct mistakes in programming a tune. If you single-step through a tune in MANUAL and come across a mistake, it's a simple matter to move the READ/WRITE switch, S2, to the WRITE position and program in the correct note...but we're getting ahead of ourselves. We'll completely discuss how to program the Pionomatic later in this article.

The other half of IC9 is used to decode a binary 14 (1110) when it appears on the output-data bus. That is done by using IC15-b to invert the least-significant line on the output-data bus. When a 14 appears on the bus, the output of IC9-b goes high, reverse biases D4, and force feeds a clock pulse to pin 9 of inverter IC15-d. That has the effect of speeding up the clock for as long as the 14 remains on the output-data bus. Since the clock increments the note counter, IC3, immediately, the next note is put on the bus and the output of IC9-b goes low again. That lets you program a temporary speedup in the clock and is used when you want a definite attack on a note or a half rest between notes.

Next time

When we continue, we'll finish up our look at how the Pianomatic works and then begin the construction. By the way, the project is built on five PC boards, two of which are double-sided. While the board patterns will appear in the next part of this article, you can order the boards from the source listed in the Parts List.

R-E