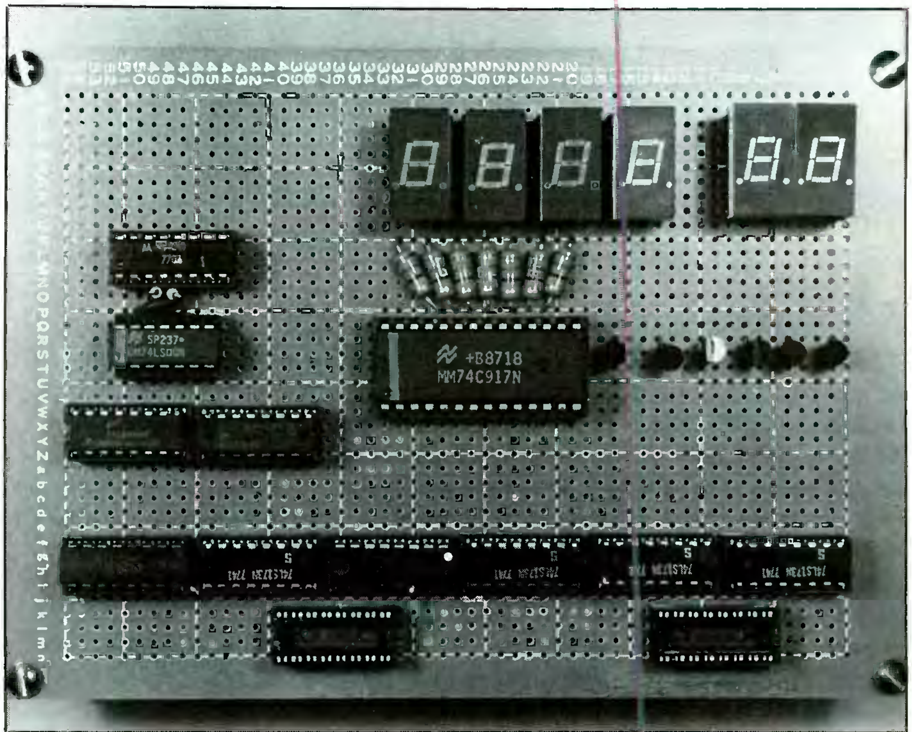
BCD-to-Hex Converter/Display

Easily converts and displays binary-coded-decimal data in hexadecimal format

By Lloyd W. Redman



National Semiconductor makes an integrated circuit that offers an ideal solution to the problem of having to convert binary-coded-decimal (BCD) data into the hexadecimal format. The six-digit hex display controller/driver MM74C917 chip decodes and displays, on separate numeric display devices, 24 bits of hex data from a BCD-format source. This gem of a chip is just what you need to relieve you of the headache of having to laboriously make BCD-to-hex conversions, either mentally or with a special type of calculator.

The BCD-to-Hex Converter/Display project described here takes full advantage of the National chip. It offers a full six digits of display that requires no interpreation. Just feed in BCD data and numeric displays automatically show its hex equivalent. The project can be used to convert and display up to 24 bits of BCD data from any source, as long as the data is latched (temporarily stopped) to provide a stable display.

About the Circuit

When designing a decoder/display driver circuit, several functions must be performed. The sequence of events is illustrated by the block diagram shown in Fig. 1.

To begin with, the BCD data to be displayed must be latched (temporarily stopped) at the Data Source. Next, the latched data must be switched, four bits at a time, by the Electronic Switch to a BCD-to-7-Segment Decoder/Driver. This section decodes the binary data to hexadecimal format and routes it to the appropriate decade in the display string (DISP1 through DISP4). Finally, the proper segments of the appropriate display decade must be turned on, which is accomplished with another Electronic Switch under control of the Electronic Switch Control & System Clock block.

Normally, the same segment turn-on information is sent to all displays simultaneously. Using a multiplexing technique, only one decade in the display is switched on a any given instant. The multiplex switching is accomplished at a rapid enough rate that the eye perceives all display decades to be on simultaneously, each with its appropriate segments lit, to display the correct data.

The 74C917 six-digit hex display controller/driver chip is the workhorse of this project. It performs nearly all the functions illustrated in Fig. 1. To accomplish this, the chip has on-board a number of circuits, which are diagrammed in Fig. 2.

Referring to Fig. 2, BCD data (except the decimal point) is presented at inputs a, b, c and d of the Input

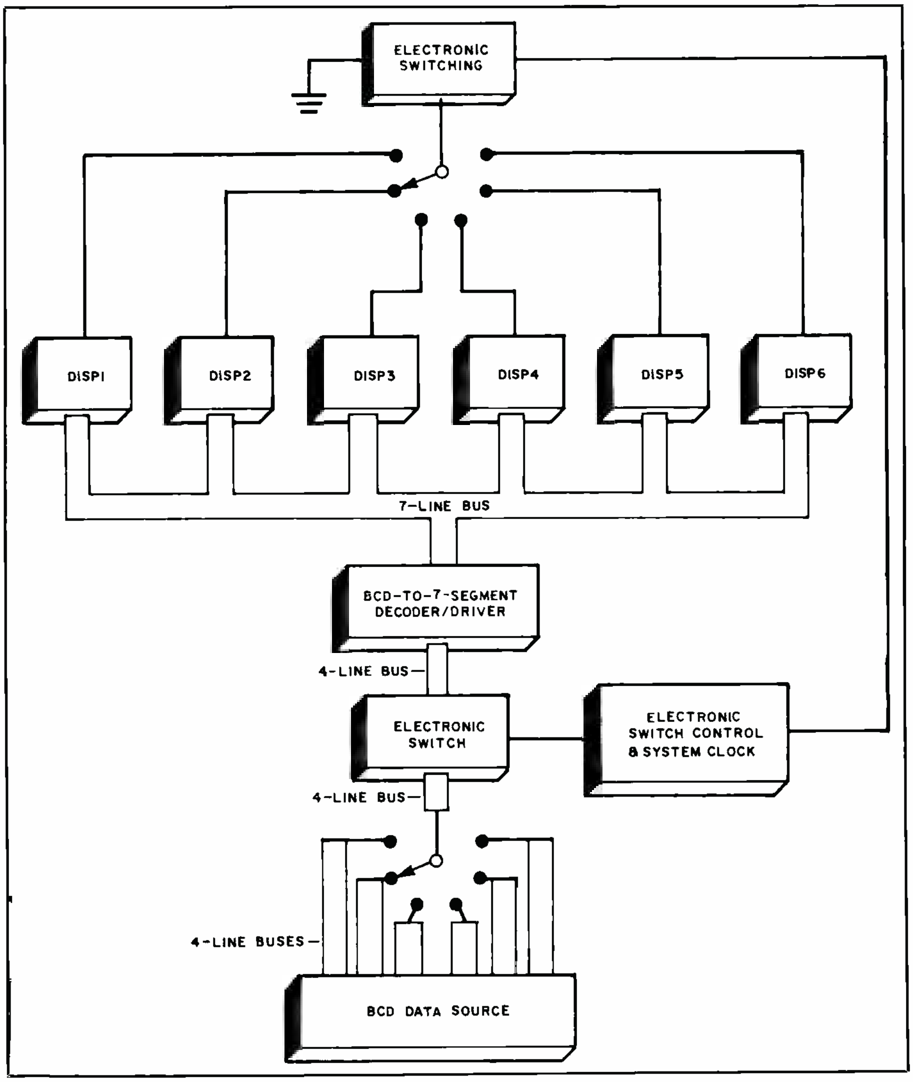


Fig. 1. Block diagram of the subsections that make up the project.

Data Buffers. This data is written into internal registers M1 through M6 when $\overline{WE}$ (write enable) and $\overline{CE}$ (chip enable) are low. (When implemented in the project presented here, $\overline{CE}$ is permanently wired low.)

When WE goes from low to high, the data written into the registers is latched. Address information is furnished the 74C917 from a 74LS390 (*IC4* in Fig. 3 complete schematic diagram of project) dual decade ripple counter. An internal oscillator running at about 350 Hz switches the BCD data from the internal registers to the 16 × 7 ROM where it is decoded to hexadecimal format. When SOE goes low, segment drive data is switched to the proper decade in the display and turns on that decade.

Referring now to Fig. 3, the display system clock generator consists of two stages in 4049 CMOS hex inverting buffer *IC2*, wired here as an astable or free-running multivibrator. Clock frequency is determined by the values of *R9* and *C1*. Ideally, operating frequency of the clock generator is calculated using the formula f = 1/2.2RC. The main objective in selecting the values of the resistor and capacitor was to have a digit-select frequency that was high enough to obviate perceptible flicker of the lighted segments in the display.

The output at pin 2 of *IC2* goes to the input at pin 1 of counter *IC4*. The internal counter to which pin 1 of *IC4* connects operates as a BCD decade counter. The output at pin 3 of this counter furnishes the clock signal that is fed to pins 8 of 74LS173 quad D-type flip-flops *IC6* through *IC11*. The output at pin 5 of *IC4* goes to the pin 10 clock-enable inputs of the same ICs.

The output at pin 6 of *IC4* provides the clock input to pin 15 of the second counter inside this chip and the write-enable ($\overline{WE}$) signal to pin 2 of 74C917 display controller/driver *IC1*. The output at pin 7 of *IC4* connects to segment output-enable ($\overline{SOE}$) pin 15 of *IC1*.The duty cycle of the pulse train fed to the *IC1* pin 15 input determines the segment on/off time and, subsequently, the brightness of the lighted segments in the display.

If you wish to temporarily reduce power dissipation, you can do either of two things to extinguish the display. You can switch off the +5 volts to the entire circuit. Alternatively, you can install an spdt switch in the line that goes from pin 7 of *IC4* (one switch throw, or stationary contact) and pin 16 of *IC1* (the switch pole, or toggle) and run a line from the +5-volt bus to the remaining switch throw. With this arrangement, when you want to extinguish the display, you simply set the switch to its +5V position.

If you want to be able to adjust the brightness of the display, you can drive pin 1 of *IC1* with a variable-frequency pulse generator. Such a generator can easily be assembled around a commonly available 555 or other timer chip. Schematic diagrams for building a variable-frequency pulse generator can be found in a wide variety of electronics magazine articles and books.

The second ripple counter inside *IC4* is also wired as a BCD decade counter. Its pins 10 and 11 outputs go to the inputs of one gate inside

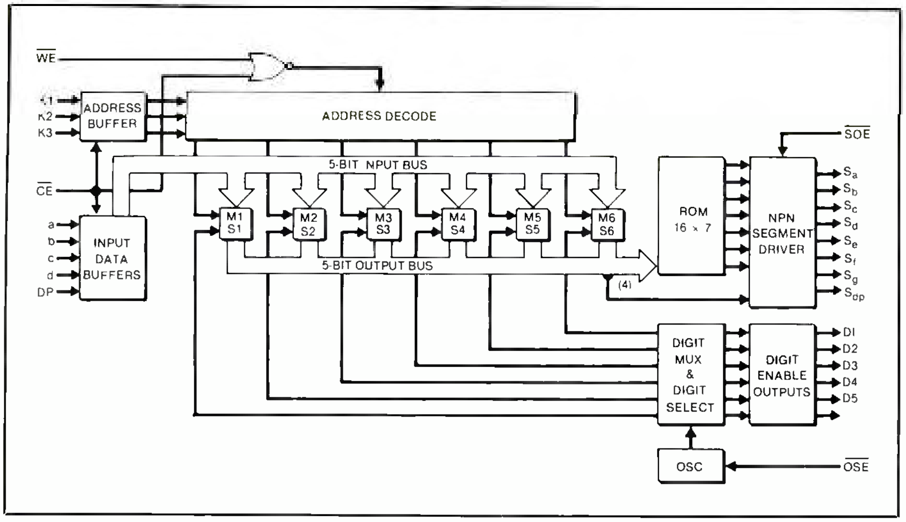


Fig. 2. The 74C917 six-digit hex display controller/driver chip around which project is built contains circuitry that performs nearly all functions diagrammed in Fig. 1.

84LS00 quad NAND gate *IC3* at pins 9 and 10, respectively. The output of the second counter inside *IC4* is inverted by a second gate inside *IC3* and is available at pin 11. This inverted signal is fed back to master-reset pin 14 of *IC4*.

The second ripple counter inside *IC4* counts from 0 to 5 and resets to 0. The outputs at pins 13, 11 and 10 generate the address code for internal registers of *IC1*. These outputs also connect to 74LS138 1-of-8 decoder *IC5* at pins 1, 2 and 3, respectively. Though *IC5* is in reality a 1-of-8 decoder, it is wired here as a 1-of-6 decoder.

BCD data is temporarily stored in *IC6* through *IC11* before it is switched from pins 6, 5, 4 and 3 of these flip-flops to the A, B, C and D inputs of *IC1* at pins 3, 4, 5 and 6, respectively. Notice in the schematic that the clock enables (E1) pins 9 of *IC6* through *IC11* are wired to ground (logic low).

When the E2 clock enables at pins 10 of *IC6* through *IC11* are low, the next low-to-high transition of the clock signal, connected to pin 7 of each of these flip-flops, loads the BCD data into the chips. When the E2 pin is high on any flip-flop, the next high-to-low transition of the clock signal latches the BCD data into that flip-flop.

Outputs of *IC6* through *IC11* operate independently of the inputs. Output-enable ($\overline{OE2}$) pin 2 in all six cases is wired to ground (logic low). When output-enable ($\overline{OE1}$) pin 1 goes low, the data latched into the flip-flops appears at output pins 3, 4, 5 and 6. The signal on pin 2 is generated by *IC5* operating as a 1-of-6 decoder/demultimplexer. When this signal is high, the pins 3 through 6 outputs are in high-impedance state. Thus, all flip-flop outputs can be connected to a common bus feeding the inputs of *IC1*.

Power for the project is supplied by a suitable 5-volt dc power supply. If you do not have one handy, you can build the one shown schematically in Fig. 4. This is a common full-wave supply with built-in voltage regulation provided by *IC12*.

Construction

You can assemble this project using any of a number of traditional wiring techniques. If you wish, for example, you can design and fabricate a printed-circuit board on which to mount and wire together the various

PARTS LIST

Semiconductors

D1 thru D4—1N4003 or similar silicon rectifier diode
DISP1 thru DISP6—Common-cathode LED numeric displays to mount in 14-pin DIP socket
IC1—74C917 six-digit hex display controller/driver
IC2—CD4049 hex inverting buffer
IC3—74LS00 quad two-input NAND gate
IC4—74LS390 dual decade ripple counter
IC5—74LS138 1-of-8 decoder/ ultiplexer
IC6 thru IC11—74LS173 Quad D-type flip-flop with three-state outputs
IC12—7805 +5-volt regulator
Q1 thru Q6—2N3904 or similar silicon npn transistor

Capacitors

C1—47-pF ceramic disc
C2—0.1-μF ceramic disc
C3—2,500-μF, 16-volt electrolytic
C4—1-μF, 9-volt electrolytic

Resistors (¼-watt, 5% tolerance)

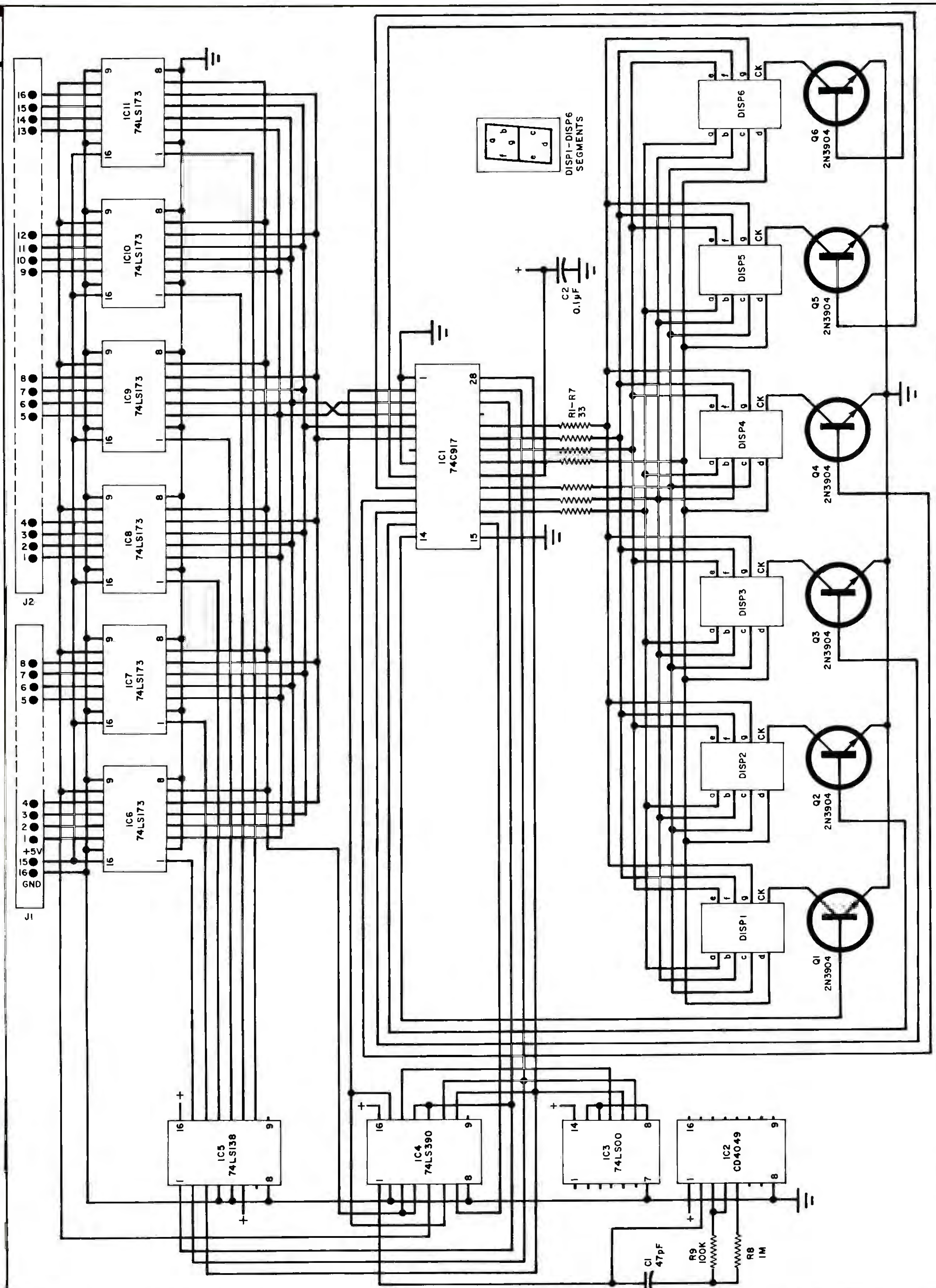
R1 thru R7—33 ohms
R8—1 megohm
R9—100,000 ohms

Miscellaneous

J1,J2—16-pin DIP IC socket
T1—12.6-volt, 1-ampere power transformer
Printed-circuit board or perforated board with holes on 0.1-inch centers and suitable Wire Wrap or soldering hardware (see text); sockets for all DIP ICs and LED displays; two 16-conductor ribbon cables with 16-pin headers; suitable enclosure; LEDs, 330-ohm resistors, CD4060 divider chip and spst switch for testing purposes (see text) machine hardware; hookup wire; solder; etc.

Note: The 74C917 display controller/driver is available by mail order from Digi-Key, P.O. Box 677, Thief River Falls, MN 56701-9988 or Jameco Electronics, 1355 Shoreway Rd., Belmont, CA 94002.

Fig. 3. Schematic diagram of all circuitry, except power supply, used in the project.


IC1 74C917
IC2 CD4049
IC3 74LS00
IC4 74LS390
IC5 74LS138
IC6 74LS173
IC7 74LS173
IC8 74LS173
IC9 74LS173
IC10 74LS173
IC11 74LS173
DISP1
DISP2
DISP3
DISP4
DISP5
DISP6
Q1 2N3904
Q2 2N3904
Q3 2N3904
Q4 2N3904
Q5 2N3904
Q6 2N3904
DISP1-DISP6 SEGMENTS
R1-R7 33
C2 0.1µF
C1 47pF
R9 100K
R8 1M
J1
J2
+5V
GND

Master Wiring List

IC1 (74C917)

From Pin	To
1	Ground
2	IC4 pins 6,15
3	IC6 thru IC11 Pin 3
4	IC6 thru IC11 Pin 4
5	IC6 thru IC11 Pin 5
6	IC6 thru IC11 pin 6
7	No Connection
8	Ground
9	Q6 Base
10	Q5 Base
11	Q4 Base
12	Q3 Base
13	Q2 Base
14	Q1 Base
15	Ground
16	IC4 Pin 7
17	R1
18	R2
19	R3
20	+ 5 Volts
	C2
21	R4
22	R5
23	R6
24	R7
25	No Connection
26	IC4 Pins 12,13
	IC5 Pin 1
27	IC3 Pin 9
	IC4 Pin 11
	IC5 Pin 2
28	IC3 Pin 10
	IC4 Pin 10
	IC5 Pin 3

IC2 (CD4049)

From Pin	To
1	+ 5 Volts
2	C1
	IC4 Pin 1
3	IC2 Pin 4
	R9
5	R8
6	No Connection
7	No Connection
8	Ground
9	No Connection
10	No Connection
11	No Connection
12	No Connection
13	No Connection
14	No Connection
15	No Connection
16	No Connection

IC3 (74LS00)

From Pin	To
1	No Connection
2	No Connection
3	No Connection
4	No Connection
5	No Connection
6	No Connection
7	Ground
8	IC3 Pins 12,13
11	IC4 Pin 14
14	+ 5 Volts

IC4 (74LS390)

From Pin	To
1	IC2 Pin 2
	C1
2	Ground
	IC4 Pin 8
3	IC4 Pin4
	IC6 thru IC11 Pins 7
5	IC6 thru IC11 Pin 10
6	IC4 Pin 6
7	IC1 Pin 16
9	No Connection
16	+ 5 Volts

IC5 (74LS138)

From Pin	To
4	Ground
5	Ground
6	+ 5 Volts
7	No Connection
8	Ground
9	No Connection
10	IC11 Pin 1
11	IC10 Pin 1
12	IC9 Pin 1
13	IC8 Pin 1
14	IC7 Pin 1
15	IC6 Pin 1
16	+ 5 Volts

IC6 (74LS173)

From Pin	To
2	Ground
	IC6 Pins 8,9,15
	IC7 thru IC11 Pins 2, 8,9,15
	J1 Pin 16
10	IC7 thru IC11 Pin 10
11	J1 Pin 4
12	J1 Pin 3
13	J1 Pin 2
14	J1 Pin 1
16	+ 5 Volts
	IC7 thru IC11 Pin 16
	J1 Pin 15

IC7 thru IC11 (74LS173)

From			To		
IC7	Pin	11	J1	Pin	8
		12			7
		13			6
		14			5
IC8	Pin	11	J2	Pin	4
		12			3
		13			2
		14			1
IC9	Pin	11	J2	Pin	8
		12			7
		13			6
		14			5
IC10	Pin	11	J2	Pin	12
		12			11
		13			10
		14			9
IC11	Pin	11	J2	Pin	16
		12			15
		13			14
		14			13

Miscellaneous

From		To
IC12	IN	C3 +
		Bridge +
	COM	C3 – ,C4 –
		Bridge –
		Ground Bus
	OUT	C4 +
		+ 5-Volt Bus
DISP1-DISP6		
	Pin a	DISP2-DISP6 Pin a
		R1
	b	DISP2-DISP6 Pin b
		R2
	c	DISP2-DISP6 Pin c
		R3
	d	DISP2-DISP6 Pin d
		R4
	e	DISP2-DISP6 Pin e
		R5
	f	DISP2-DISP6 Pin f
		R6
	g	DISP2-DISP6 Pin g
		R7
	CK	Q1 Collector
DISP2	Pin CK	Q2 Collector
DISP3	Pin CK	Q3 Collector
DISP4	Pin CK	Q4 Collector
DISP5	Pin CK	Q5 Collector
DISP6	Pin CK	Q6 Collector
Q1-Q6	Emitter	Ground
C2		Ground
C1/R9		R8

components. Alternatively, you can use perforated board with holes on 0.1-inch centers and suitable Wire Wrap or soldering hardware to mount and wire together the components. Whichever way you go, though, be sure to use sockets for all ICs and the LED numeric displays.

As shown in the lead photo, the prototype of the project was assembled on perforated board. Measuring 6⅝ × 4½ inches, the Radio Shack Cat. No. 276-147 has a copper pad for each hole on the wiring side of the board. You can use this or any other similar board or even perforated board that has no pads around the holes if you go this route. To provide stability, assuming pad/hole board and the point-to-point wiring technique, it is suggested that you solder at least the corner pins of each IC socket to the pads surrounding them.

Begin construction by installing the IC and display sockets. Also mount into place between the edge of the board and the six sockets for *IC6* through *IC11* 16-pin DIP sockets *J1* and *J2* (shown unoccupied in the lead photo). If you are using a pc board or pad/hole perforated board, solder the pins of the sockets into place. If you are point-to-point wiring the circuit, it is a good idea to mark the pin 1 position for each socket on the wiring side of the board. Alternatively, you can place a commercial plastic ID label on which the pin numbers are printed for each socket location. Do *not* plug any ICs or displays into the sockets until after you have performed initial voltage checks and are certain that all wiring is correct.

Again assuming you are using a pc board or pad/hole perforated board, install the resistors and then the capacitors in their respective locations and solder both leads of each into place. Having come this far, you are ready to proceed with wiring together the sockets and components. (If you are using a pc board, they are already wired together.)

A fairly foolproof method of wiring any project using the point-to-point technique is to make up a Wiring List that details every wire run and connection and check off each as it is made. The complete Wiring List for this project is shown elsewhere in this article. Carefully following each step as detailed in it should yield a working project the first time out.

Next, using the Wiring List and an ohmmeter or audible continuity tester, check all runs and connections for continuity. When you obtain the proper indications in all cases, assemble the power-supply circuit (if there is room for them, you can mount the rectifier diodes, two capacitors and regulator *IC12* on the circuit-board assembly. Do not attempt to mount the power transformer on the board. If you wish, you can incorporate a POWER switch and 1-ampere slow-blow fuse in a holder into the primary side of the power transformer in the traditional manner.

Select a suitable enclosure for the project. It can be all plastic, all metal or a combination of the two. The enclosure must be large enough to accommodate the circuit-board assembly and power transformer without crowding and have sufficient front-panel room for the POWER switch and a bayonet-type fuse holder if you decide to use these two components.

Machine the enclosure as needed. That is, drill mounting holes in the floor panel for the circuit-board assembly and power transformer and an entry hole for the ac line cord through the rear panel. Determine exactly where in the top panel to make the cutout for the six-decade numeric display's window and cut a suitable slot for it. Then cut narrow slits through the rear wall panel near *J1* and *J2* through which to route the two input cables. Make these slits only wide enough to pass through the ribbon-type input cables. If you are using the POWER switch and fuse, also drill holes in which to mount them through the front panel.

If you drilled the holes or cut the display slot through metal panels, deburr them to remove sharp edges. Then mount the power transformer in place with suitable machine hardware, sandwiching the mounting tab of a two-lug terminal strip (neither lug connected to the mounting tab) between the nut and one tab of the transformer. Connect and solder the two secondary leads of the transformer to the appropriate points in the bridge rectifier arrangement in the power supply.

Crimp but do not solder the primary leads of the power transformer to the lugs of the terminal strip. If the line-cord entry hole is through a metal panel, line it with a rubber grommet. Pass the unfinished end of the line cord through the hole and into the enclosure. Tie a strain-relieving knot in it about 6 inches from the unfinished end inside the enclosure.

Tightly twist together the fine wires in each line-cord conductor and sparingly tin with solder. Crimp and solder one line-cord conductor to one lug of the terminal strip, and solder the primary lead of the transformer already in place on this lug.

Mount the fuse holder and POWER switch (if you are using them) in their holes on the front panel. Connect and solder a suitable length of hookup wire from one lug of the switch to one lug of the fuse holder. Similarly, connect and solder a hookup wire to the other lug of the fuse holder, route the other end to the unsoldered lug of the terminal strip. Crimp the free end of this wire to the lug and solder it and the primary lead already occupying the same lug. Then separate the line cord conductors inside the enclosure to within 1 inch of the strain-relieving knot. Crimp and solder the unattached conductor to the unoccupied lug of the POWER switch.

The input cables for the project consist of standard 16-conductor ribbon-cable assemblies terminated in 16-pin DIP headers. Two separate input cables are needed. Cut off and discard one header from each cable.

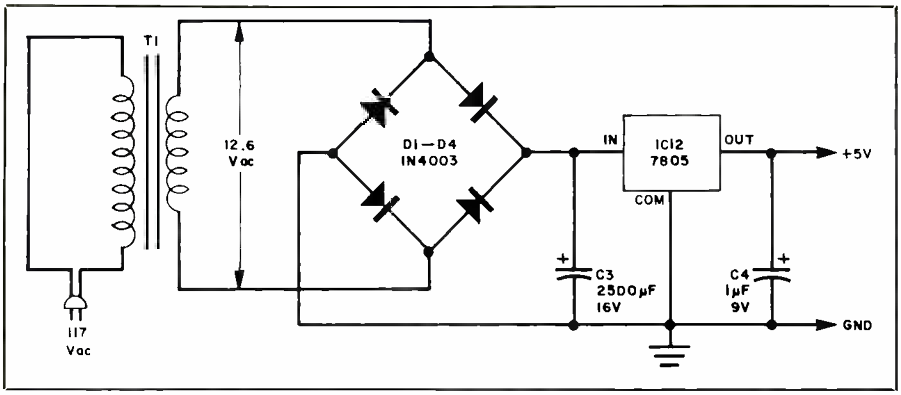
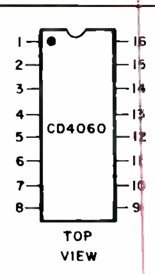


Fig. 4. Schematic diagram of a suggested 5-volt regulated dc power supply for use with project.



OUTPUTS		
PIN NO.	CLOCK DIVISION	OUTPUT IN Hz
1	4,096	5
2	8,192	2
3	16,384	1
4	64	325
5	32	650
6	128	162
7	16	1,300
13	512	40
14	256	80
15	1,024	20

Fig. 5. A CD4060 divider chip can be used to slow down project's clock oscillator for easy observance of signal activity via a logic probe or discrete LEDs.

Then carefully separate the conductors at the cut ends a distance of about 3 inches. Strip ¼ inch of insulation from the ends of all cut-end conductors, tightly twist together the exposed fine wires in each case and sparingly tin with solder. Use heat judiciously to minimize charring the insulation.

Pass the unprepared ends of the cables through the narrow slots you cut through the rear panel from the *inside* of the enclosure. Plug the headers at the ends of the cables into the *J1* and *J2* IC sockets. Leaving about 1 inch of slack in each cable inside the enclosure, apply a liberal bead of silicone adhesive on both sides of the cables to secure them in place against the rear panel. Allow the adhesive to fully cure, at least overnight, before proceeding.

When the adhesive has cured, terminate the unfinished ends of the conductors in suitable connectors for your expected applications.

System Checkout

If you incorporated the POWER switch and fuse into your project, place a fuse into its holder. Clip the common lead of a dc voltmeter or a multimeter set to the dc-volts function and set the meter's range selector to a position that will easily display 5 volts. Bear in mind that no ICs (except regulator *IC12* in the power supply) or LED numeric displays should be plugged into the sockets on the circuit-board assembly for preliminary voltage tests.

Plug the line cord of the project into an ac outlet. As you perform voltage checks with the meter, make absolutely certain that you do not touch or otherwise come in contact with the primary circuit of the power transformer. Potentially lethal 117 volts will be present at the terminal-strip lugs and the lugs of the POWER switch and fuse holder.

Turn on power to the project by setting the POWER switch to its "on" position, assuming you are using this switch. If you are not using the switch, dc power is automatically delivered to the various points in the circuit when you plug in the line cord.

With power applied, touch the "hot" probe of the meter to pin 20 of the *IC1* socket and note the reading obtained. It should be approximately +5 volts. If you obtain this reading, touching the "hot" probe to pin 1 of the *IC2* socket should also yield a +5-volt reading. Touching the "hot" probe to pin 14 of the remaining 14-pin and pin 16 of the remaining 16-pin IC sockets should yield the same +5-volt reading.

If you fail to obtain the proper reading at any of the indicated IC socket pins, immediately power down the circuit and pull the line cord from the ac outlet. Rectify any wiring error(s) or reverse-polarity diode or/and filter capacitor connections you might have made in the power-supply section or errors in wiring you might have made in the rest of the circuit before proceeding to operational checks.

Once you are certain of your wiring, power down the project by pulling the plug from the ac outlet. Allow sufficient time for the charges to bleed off the filter capacitors in the power supply. Then carefully plug the CD4049 into the *IC2* socket. Make sure that no IC pins overhang the sockets or fold under between devices and sockets.

To accurately check clock generator *IC2*, you should use an oscilloscope or frequency counter. If you have access to neither, you can use a CD4060 divider chip to slow down the output signal from *IC2* so that it can be verified with a logic probe.

Plug the CD4060 chip into a small solderless breadboarding socket. Using suitably long flexible wire leads, connect pins 8 and 12 to circuit ground and pin 16 to the +5-volt buses in the project. Similarly, connect a lead from output pin 11 to pin 1 of the *IC4* socket in the project.

Power up the project. If you have a scope or counter, monitor the output of the clock generator at pin 2 of *IC2*. You should obtain a frequency reading at this point of approximately 20.8 kHz. If you are using the

CD4060 circuit, refer to the table in Fig. 5 for details of where to pick off the divided signal for monitoring with a logic probe.

The most-accurate reading obtained is with an accurately calibrated frequency counter. Of slightly lesser accuracy is scope monitoring, while use of a logic probe simply gives an indication of signal activity. If you obtain any signal activity, regardless of which monitoring method you employ, you can assume that the clock oscillator is working.

Having verified that the clock oscillator is working, pull the project's line cord from the ac receptacle, allow the charges to bleed off the filter capacitors in the power supply and then install a 74LS390 in the *IC4* socket and a 74LS00 into the *IC3* socket. Again, make sure the pins of the ICs (and all subsequent ICs and LED numeric displays) engage the socket pins.

Connect separate light-emitting diodes through 330-ohm current-limiting resistors to the outputs of *IC4* at pins 2, 5, 7, 10, 11 and 13. The cathodes of the LEDs go to the specified pins on the IC, while the anodes go to the +5-volt bus through the current-limiting resistors.

Leave the CD4060 still connected to the project as described above. Then temporarily connect one of the slow outputs (see Table in Fig. 5) to input pins 1 and 15 of *IC4*.

Power up the project and observe the LEDs for activity. If you selected a low enough frequency out of the CD4060, you should observe the LEDs flashing on and off to show the BCD count. Having verified that both counters inside *IC4* are operating properly, disconnect the project from the ac line and allow time for the charges to bleed off the capacitors.

Plug a 74LS138 into the *IC5* socket. Remove the LEDs you installed for *IC4* and temporarily connect them to pins 10 through 15 of *IC5* in the same manner as you did for *IC4*. Leave the CD4060 connected as before. Power up the project and observe the activity of the LEDs. If you selected a low enough frequency through the CD4060, you should observe the LEDs counting in a repeating 0-to-5 sequence.

With operation of *IC5* confirmed, pull the plug of the project from the ac outlet and allow the charges to bleed off the capacitors. Then temporarily tack-solder suitable lengths of hookup wire to the +5-volt or ground buses in the project and terminate the other ends at pins 1 of *IC6* through *IC11* to represent BCD data to these input pins. Disconnect the LED/resistors from *IC5*.

Carefully plug 74LS173s into the *IC6* through *IC11* sockets. Temporarily connect four of the LED/resistor combinations between pins 3 through 6 of *IC6* and the +5-volt bus in the same manner as above.

Power up the project and observe the LEDs, which should flash on and off in BCD sequence. Once you obtain LED activity, power down the project and move the LED/resistor combinations to between pins 3 through 6 of *IC7* and the +5-volt bus and repeat the test. Do this for *IC8* through *IC11* in turn to verify operation of all six latches. Once you verify operation of each stage, power down the project and remove the wires from the +5-volt bus and pins 1 of *IC6* through *IC11* and remove the LED/resistor combinations.

Plug the six LED displays into a solderless breadboarding socket to precheck all seven segments of each before installing the displays in their sockets. Connect the common cathodes of the displays to the ground bus in the project. Tack solder a suitable length of hookup wire to the +5-volt bus in the project and terminate the other end of the wire in a 330-ohm resistor. Use this test lead to check each segment in each display by plugging the free lead of the resistor into the appropriate holes for the pins that connect to segments *a* through *f* of each display.

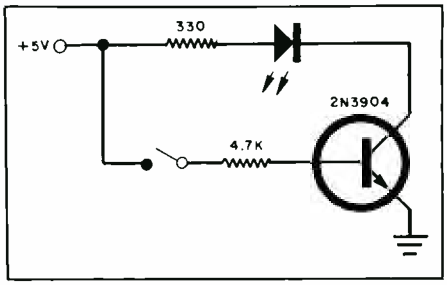


Fig. 6. A circuit for testing operation of project's transistors out-of-circuit.

You can also check each of the *Q1* through *Q6* transistors out-of-circuit. To do this, breadboard the circuit shown in Fig. 6. The transistor shown here is the one that will be installed in the project. This test circuit is designed to prevent exceeding the maximum allowable base current for the transistors.

You verify operation of the transistor under test by powering up the project, closing the switch and observing the LED. If the LED lights with the switch closed, the transistor is good. If the LED does not light, discard the transistor and replace it with a new one.

Now that you have tested all the subsystems in your project (and corrected any wiring errors you have detected during this operation), it is time to connect the output of the clock generator to the first counter. With power turned off and no charges on the filter capacitors in the power supply, install the 74C917 chip in the *IC1* socket, employing the same precautions you would use for handling any other MOS-type device.

Power up the project and check operation of the complete system. Change the BCD inputs to flip-flops *IC6* through *IC11* and verify that the LED numeric displays show the corresponding hex signals.

To use the project, simply clip the leads of its input cables to the appropriate points in the circuit under test. Power up the circuit being tested and the project and observe the numeric displays. That is all there is to it!