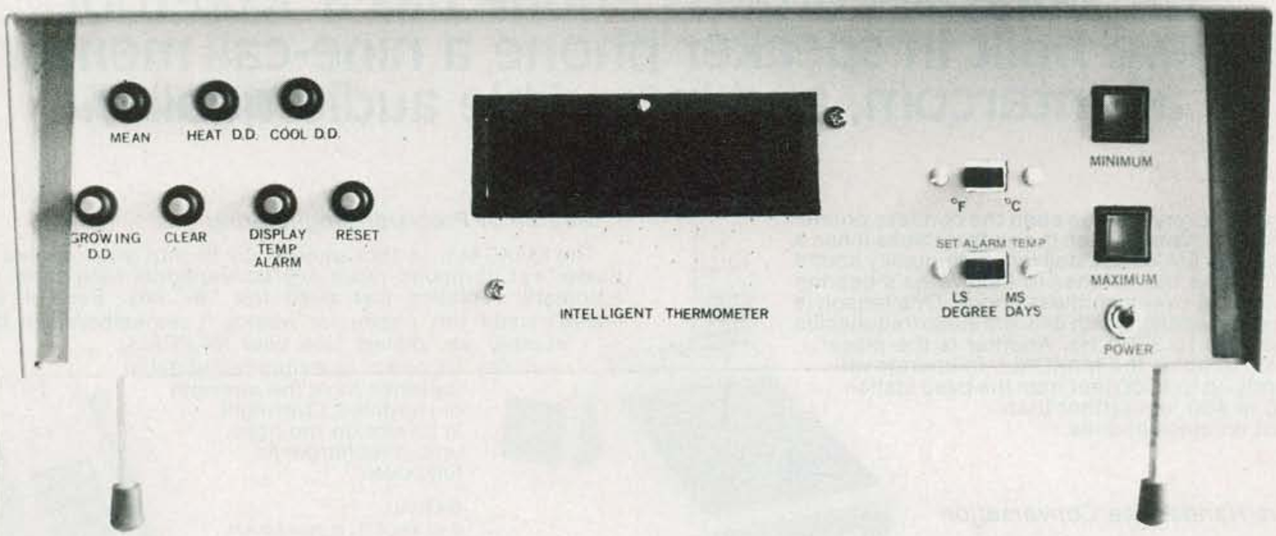


Build The Intelligent Thermometer

Part 1

A microprocessor and a programmed EPROM are used in this sophisticated circuit to measure and analyze changes in temperature

By Tom Fox

MOST people associate the word "microprocessor" with computers. However, there are many sophisticated devices besides computers that use microprocessors. One such device is the Intelligent Thermometer described here. It is called "intelligent" because the particular program in its memory allows many uses besides simple temperature measurements.

For instance, the Intelligent Thermometer analyzes the temperature data and stores the results in its semi-permanent memory. It measures temperatures between −56°F and +199°F (−49°C and 93°C) and does it with an accuracy better than ±1°F over its entire range. It stores the minimum and maximum temperatures, and calculates and stores the mean temperature up to a 255-day interval with an accuracy better than that of the U.S. Weather Service. The Intelligent Thermometer also calculates and stores heating degree-days (base 65°F), cooling degree-days (base 75°F) and growing degree-days (base 42°F). Up to 9999 degree-days can be stored in each of its degree-day registers.

The analyzing portion of the thermometer has three outputs that can be used to activate a relay or buzzer. The first signals a temperature of 32°F or below, while the other two signals indicate a temperature either above or below a preset threshold of the user's choice.

The temperatures and degree-days can be displayed in either Fahrenheit or Celsius depending on the setting of a switch. (Celsius degree-days are rounded off to the nearest 100.) An optional battery allows memory retention during power failures.

The versatility of the thermometer is further enlarged by the user's ability to erase and re-program the EPROM—or plug a new EPROM into the socket. For instance, the thermometer could be transformed into an energy-saving digital thermostat by changing the EPROM and adding two relays.

About the Circuit. A block diagram of the thermometer is shown in Fig. 1. Its memory map is given in Fig. 2. The 6802 CPU is basically the same as a 6800 with the added features of an internal clock oscillator and driver, plus 128 bytes of RAM. The first 32 bytes of RAM can be retained in the low-power

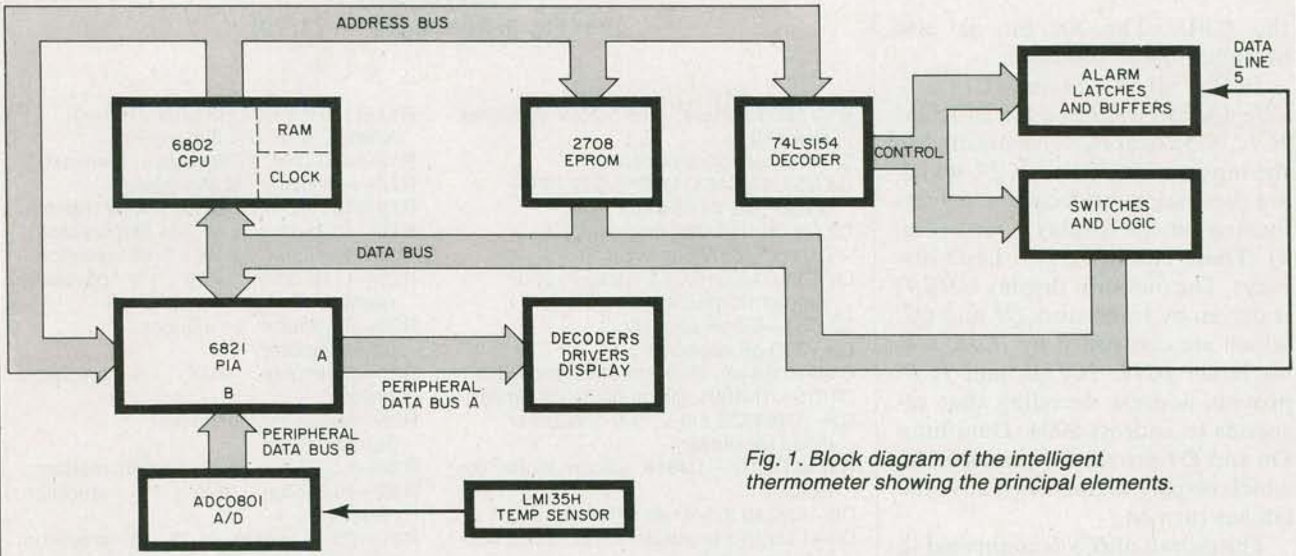


Fig. 1. Block diagram of the intelligent thermometer showing the principal elements.

mode, thus allowing memory retention in the event of power failure.

The entire program is stored within EPROM *IC12* and uses approximately 850 bytes of the 1024-byte capability.

The temperature is sensed by *D9*, a precision temperature sensor having a nearly linear response and a low dynamic impedance that allows remote sensing. The voltage reference is *D8*. The amplified (via *IC11*) temperature signal is applied to *IC9*, an A/D converter that converts the data into one byte of digital information. Each bit of the A/D converter is equivalent to 1°F. Byte 00000000 equals −56°F while byte 11111111 equals 199°F.

Side A of peripheral interface adapter *IC7* is programmed as the output with its data bus connected to *IC28* and *IC29*, a pair of 7-segment decoder/drivers. Side B is programmed as the input and is connected to the *IC9* (A/D converter) data bus.

Four-line to 16-line decoder *IC21* provides address decoding for the switches and output latches.

As shown in Fig. 3A the CPU, *IC8*, has its *reset* (pin 40) connected both to its own *read enable* (pin 36) and *IC7's reset* (pin 34). When the 6802's *reset* is brought high after being low for at least 20 ms, the CPU reset sequence starts. The 6802 first checks what 2-byte address is stored at locations FFFE and FFFF (each location contains 1 byte of the address) and then goes to this address which is the start of the program.

The circuit consisting of *IC6A*, *IC5A*, and associated components has a twofold purpose—it resets *IC7* and *IC8* during power-up, and provides a *read enable* (RE) signal for the CPU. The RE signal is arranged so that it goes low before V_{cc} drops below 4.75 V. This is necessary to keep erroneous information from being stored during a power failure. Pin 3 of *IC6A* monitor's the V_{cc} supply (+5 V). Potentiometer *R9* is set so that the voltage at pin 3 is slightly below that at pin 2, which monitors the rectified and partly filtered voltage produced by *D5*, *C14*, and *R14*. This circuit responds quickly to any power-down, or brown-out condition. When the power-line voltage starts to drop, the voltage at pin 2 drops below that at pin 3 and the *IC6A* output jumps to near 5 V. Schmitt trigger, *IC5A*, senses that *IC6A*'s output is starting to rise and produces a low output when this voltage exceeds about 3 V. Thus RE drops low several microseconds after V_{cc} drops more than about 2%—in time to ensure that the contents of the RAM are unchanged.

As mentioned earlier, this circuit also provides the "power-up" reset signal for the CPU and peripheral interface adapter (PIA). When the line voltage rises rapidly (for instance, when first turned on), *C5* instantly raises the voltage at pin 3 of *IC6A*. Pin 3's potential is now above that at pin 2, and the reset pin's potential is brought low. The voltage at pin 3 declines exponentially to a steady-state or "normal" voltage about a half second after power-up. When the voltage at *IC6A* pin 3 falls below that at pin 2, the reset pin jumps high and starts

RAM IN 6802 RETAINABLE IN LOW-POWER STANDBY MODE	0000-001F
RAM IN 6802	0020-007F
NOT USED	0080-7FFF
PIA	8000-8003
DIS 4 (−1)	8004
NOT USED	8005-87FF
SWITCHES	8800-880D
OUTPUTS	880E, 880F
NOT USED	8810-FBFF
INTELLIGENT THERMOMETER'S EPROM PROGRAM	FC00-FFFF

Fig. 2. Memory map of the system.

the CPU. The RE pin is also brought high at this time.

In Fig. 3B, *IC15A* and *IC13* provide address decoding for EPROM *IC12*. Side A of *IC7* is connected to the inputs of *IC28* and *IC29*, which are the 7-segment decoders/drivers located on the display board (Fig. 4). These ICs drive two LED displays. The overflow display (*DIS 4*) is driven by transistors *Q1* and *Q2*, which are controlled by *IC18*, a 4-bit latch. *IC14, IC15B*, and *IC16* provide address decoding that responds to address 8004. Data lines D6 and D7 provide information on which display segments (if any) the latches turn on.

The output of *IC9* is connected to *IC7's* peripheral data bus on side B. The ADC0801 (*IC9*) 8-bit A/D converter has a total adjusted error of less than $\pm^1/_4$ LSB ($\pm^1/_4$°F). The LM135H precision temperature sensor, *D9*, behaves as a low-power zener diode with a breakdown voltage proportional to absolute temperature at +10 mV/°K. Thus at 77°F (25°C or 298.15°K) the LM135H theoretically breaks down at 2.9815 V. The LM135H operates over a −55°C to +150°C temperature range (−67°F to +302°F), and its extremely low dynamic impedance (less than 1 ohm) allows it to be used at remote locations. This sensor is almost perfectly linear (±0.3°C) over its entire range, which makes it simple to use with A/Ds, and it doesn't require a special linearizing program.

The LM336 2.5-V reference diode, *D8*, provides an unusually stable reference voltage for *IC9* as well as for the calibration circuit Although the LM336 is an integrated circuit, it acts as a low-power zener diode with an exceptionally small temperature coefficient. Diodes *D3* and *D4* and resistor *R28* trim *D8* for a minimum temperature coefficient of 1.8 mV over a 0°C to 70°C temperature range.

A calibration circuit (*IC11A, IC11B* and associated components) manipulates *D9*'s output voltage so that the thermometer is able to measure the full range of

(Continued on page 80)

PARTS LIST

(For Fig. 3. See pages 77, 78, 79)

B1—NiCd battery, 4.75-5.25 V (optional, see text)
C1—0.1-μF, 50-V capacitor
C4,C5,C10,C16,C17,C18,C19,C20—0.1-μF, 25-V capacitor
C2,C3,C9,C13,C22 through C30—0.01-μF, 25-V capacitor
C6,C11,C12,C15,C21—10-μF, 25-V tantalum capacitor
C7,C31—27-pF capacitor
C8—330-pF capacitor
C14—0.68-μF, 25-V tantalum capacitor
D1,D5—1N4001 silicon diode (or similar)
D2—1N5232B 5.6-V, 500-mW zener diode (or similar)
D3,D4,D6,D7—1N914 silicon diode (or similar)
D8—LM336 2.5-V reference diode
D9—LM135H precision temperature sensor (see note)
DIS1,DIS2,DIS3—7-segment common-anode LED display (MAN 72 or similar)
DIS4—Overflow common-anode LED display (MAN 73 or similar)
IC1—4020 14-stage binary ripple counter
IC2—4584 hex Schmitt trigger inverter
IC3—4082 dual 4-input AND
IC4—555 timer
IC5—74LS13 dual 4-input NAND Schmitt trigger
IC6,IC11—LM324N low-power quad op amp
IC7—6821 peripheral interface adapter
IC8—6802 microprocessor
IC9—ADC0801 8-bit A/D converter
IC10—74LS541 tristate octal buffer
IC12—2708 1K-byte EPROM (see note)
IC13—74LS30 8-input NAND
IC14,IC22,IC23,IC24—74LS02 quad 2-input NOR
IC15,IC16—74LS21 dual 4-input AND
IC17—74LS00 quad 2-input NAND
IC18,IC19—74LS75 4-bit latch
IC20—7407 hex buffer
IC21—74LS154 decoder
IC25—7404 hex inverter
IC26,IC27—7405 hex inverter
IC28,IC29—7447 decoder/driver
Q1,Q2—2N2222 npn transistor (or similar)
R1,R2,R8,R21,R22,R23,R24—100-kilohm, ¼-W, 5% film resistor
R3,R4—470-kilohm, ¼-W, 5% film resistor
R5,R6—1-megohm, ¼-W, 5% film resistor
R7—(see text)
R9—500-kilohm, pc trimmer potentiometer
R10—2.2-kilohm, ¼-W resistor (see text)
R11,R12,R18,R32,R33,R67,R68—1-kilohm, ¼-W, 5% film resistor
R13—470-ohm, ½-W resistor (see text)
R14—47-kilohm, ¼-W resistor
R15,R16,R17—3.3-kilohm, ¼-W resistor
R19—10-kilohm, ¼-W, 5% film resistor
R20—15-kilohm, ¼-W, 5% film resistor
R25—1120-ohm, ¼-W, 1% precision resistor
R26—2.5-kilohm, pc trimmer potentiometer
R27—20-kilohm, ¼-W, 1% precision resistor
R28—10-kilohm, pc trimmer potentiometer
R29—1.5-kilohm, ¼-W, 5% film resistor
R30—10-kilohm, ¼-W, 1% precision resistor
R31—25.16-kilohm, ¼-W, 1% precision resistor (see note)
R34 through R45—2.2-kilohm, ¼-W resistor (optional, see text)
R46,R47,R48—100-ohm, ¼-W resistor
R49 through R62—220-ohm, ¼-W resistor
R63,R64,R65,R66—270-ohm, ¼-W resistor
S1 through S9—Spst momentary-contact pushbutton switch
S10—Dpdt slide switch
S11—Spst slide switch
XTAL—4.0-MHz crystal
Misc.—IC sockets, power supply (see text), circuit boards, 2-conductor cable, case, hardware, wire, solder, etc.

Note: The following are available from Magicland, 4380 S. Gordon, Fremont, MI 49412: complete kit of parts including pc boards, all ICs, and sensor but not case, power supply, battery or cable for $179.00, postpaid. Also available separately: 2708 EPROM (programmed) for $25.00; ADC0801 for $16.50; LM135H for $9.50; 1% precision resistors for $1.75 each; LM324N for $1.25. On orders less than $5.00, add $1.00 for handling. Outside U.S., Canada, and Mexico, add $5.00 for shipping. Michigan residents, add 4% tax. The following are available from Danocinths Inc., P.O. Box 261, Westland, MI 48185: microprocessor pc board (#RW403) for $64.00; display pc board (#RW403D) for $10.85; both pc boards for $70.00; postpaid. Michigan residents, add 4% tax. The listings for programming the EPROM can be obtained free by sending a stamped, self-addressed envelope to Magicland, at the address above.

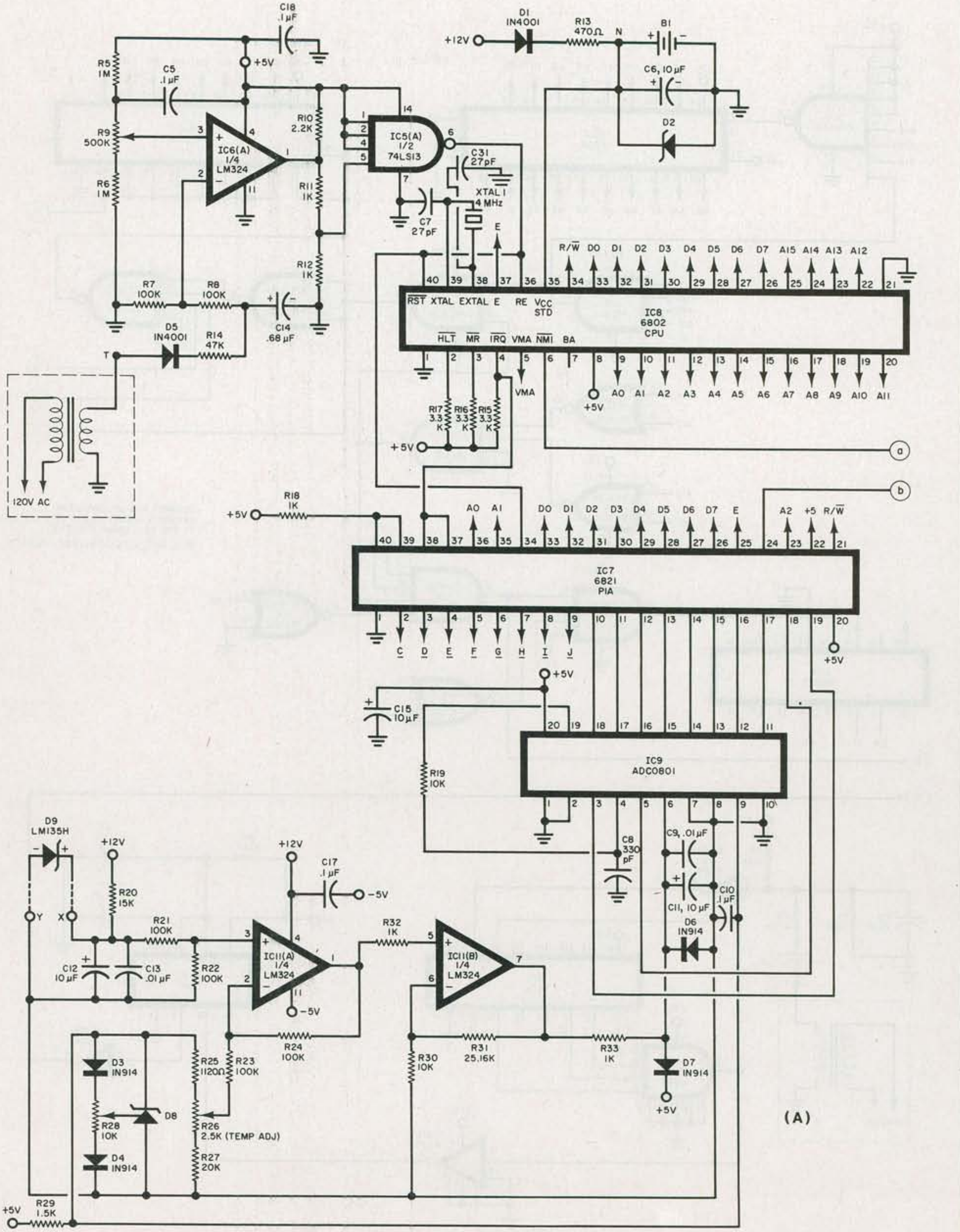
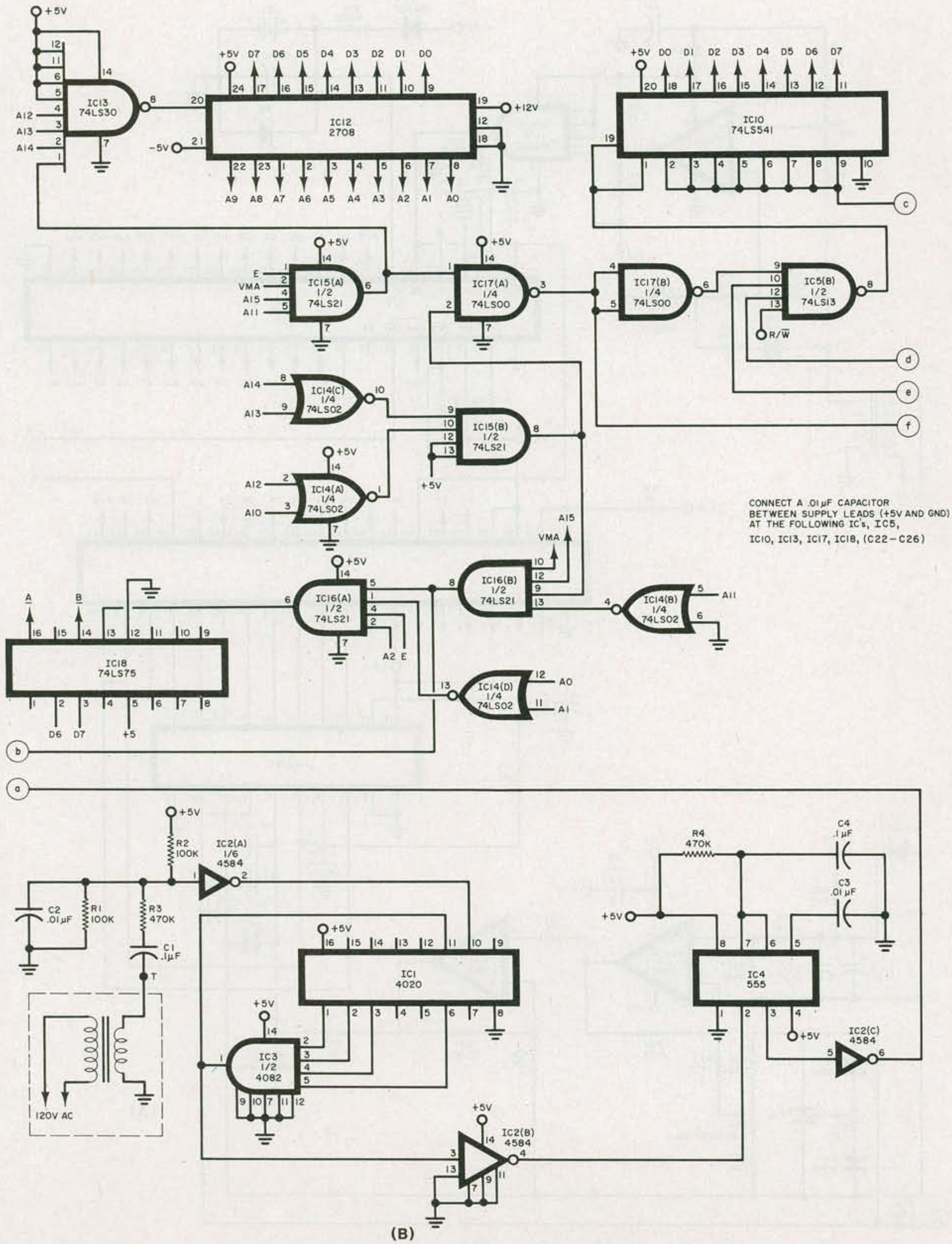


Fig. 3A. Microprocessor and PIA portions of the circuit.



(B)

Fig. 3B. EPROM and logic circuits.

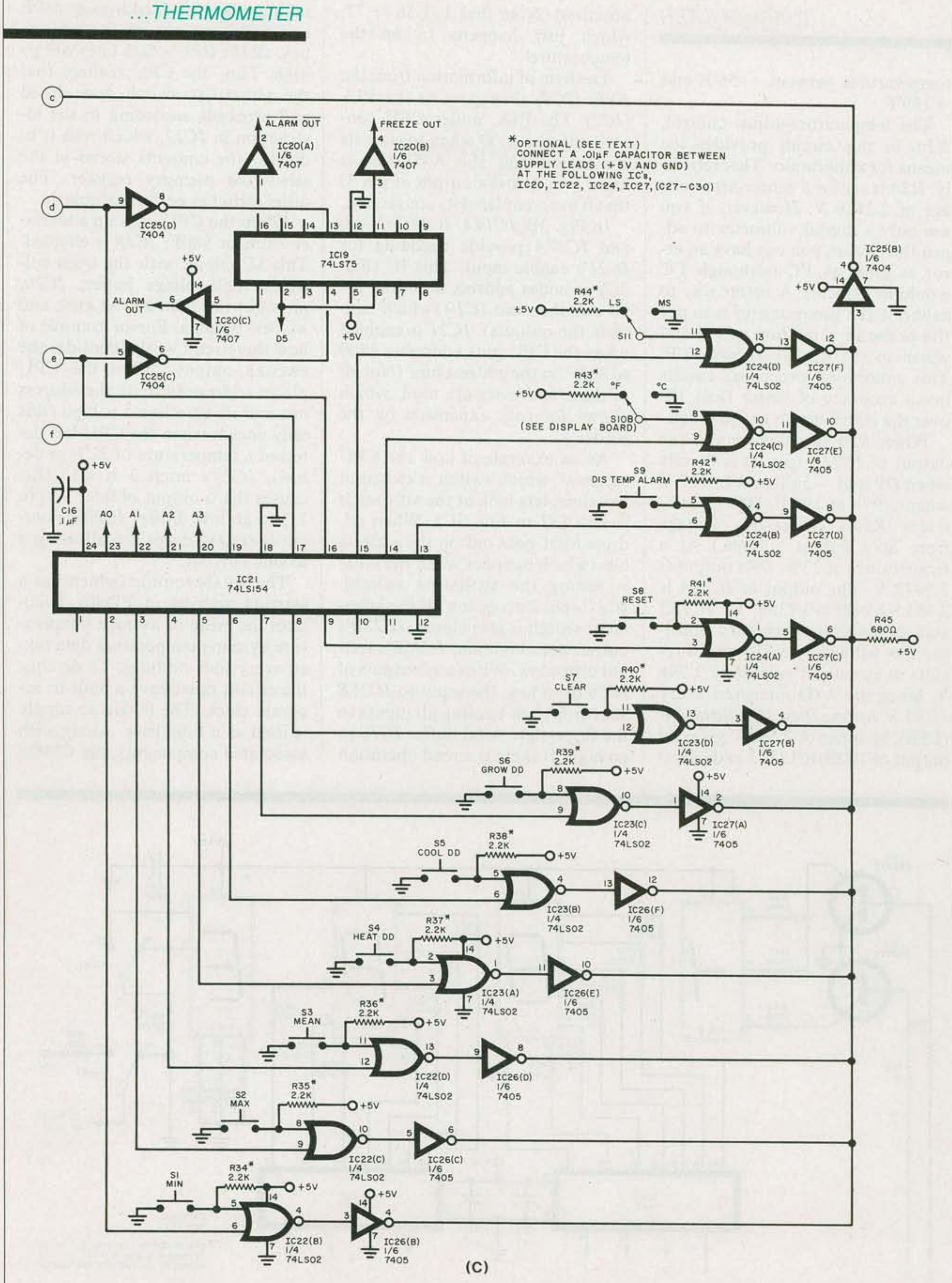


Fig. 3C. Indicating and output circuits.

temperatures between −56°F and +199°F.

The temperature-adjust control, *R26,* in this circuit provides the means for calibration. Theoretically, *R26* is set for a center-arm voltage of 2.2426 V. However, if you use only a digital voltmeter to adjust the circuit, you can have an error as great as 3°C (although 1°C would be typical). A better way to calibrate the thermometer is to put the probe in a mixture of ice and water so the display shows 32°F. This calibration procedure results in an accuracy of better than 1°F over the instrument's entire range.

When *R26* is set correctly, the output of *IC11A* (pin 1) is 0 volts when *D9* is at −56°F and 1.4167 V when *D9* is at 199°F. (*IC11A* subtracts *R26*'s center-arm voltage from *D9*'s output voltage.) At a temperature of 77°F, *D9*'s output is 2.9815 V. The output at *IC11A* is 2.9815-2.2426=0.7389 V. *IC11B* and its associated circuitry multiply this voltage by 3.516 which results in an output voltage of 2.598 V. Since the A/D interprets every .0195 V as one *least significant bit* (LSB), an input of 2.598 V gives an output of 10000101 (133 in decimal notation). Note that 133-56 = 77, which just happens to be the temperature!

The byte of information from the A/D (*IC9*) then goes to the PIA (*IC7*). The PIA, under CPU control, tells the A/D when to start its conversion and the A/D lets it know (via its $\overline{\text{INTR}}$ output at pin 5) that it has completed its conversion.

In Fig. 3B, *IC14A, IC14C, IC15,* and *IC17A* provide decoding for *IC21*'s enable input. This IC (Fig. 3C) provides address decoding for all switches and *IC19* (which controls the outputs). *IC21* is enabled when the CPU puts addresses 8800 to 880F on the address bus. (Not all of these addresses are used, which allows for easy expansion by the reader.)

As an example of how the CPU "knows" which switch is closed at any time, lets look at the MINIMUM switch (*S1* in Fig. 3C). When address 8801 goes out on the address bus (which happens when the CPU is testing the MINIMUM switch), *IC21*'s pin 2 drops low. If the MINIMUM switch is also closed, *IC22B*'s output goes high and *IC26B*'s output drops low. When any outputs of *IC26* drop low, the input to *IC25B* also drops low causing all inputs to the three-state octal buffer *IC10* to go high. If there is a read operation taking place and addresses 880E and 880F are not on the address bus, all the CPU's data lines will go high. Thus the CPU realizes that the MINIMUM switch was closed and proceeds according to the instruction in *IC12,* which tells it to display the contents stored in the MINIMUM memory register. The other switches perform similarly.

When the CPU calls up addresses 880E or 880F, *IC19* is enabled. This IC, along with the open-collector high-voltage buffer, *IC20,* provides the FREEZE, ALARM and $\overline{\text{ALARM}}$ outputs. For an example of how this circuit works, consider the FREEZE output. When the CPU places address 880F on the address bus *and* its data line 5 is high (this only occurs when the CPU has detected a temperature of 32°F or below), *IC19*'s latch 3 is set. This causes the $\overline{\text{Q}}$ output of latch 3 (pin 11) to go low. Buffer *IC20B*'s output (FREEZE) drops low allowing it to sink current.

The MEAN routine (which has a starting address of FD80) calculates the mean or average temperature by using temperature data taken every four minutes. To do this, the circuit must have a built-in accurate clock. The 60-Hz ac supply is used as a time base. Along with associated components, the CMOS

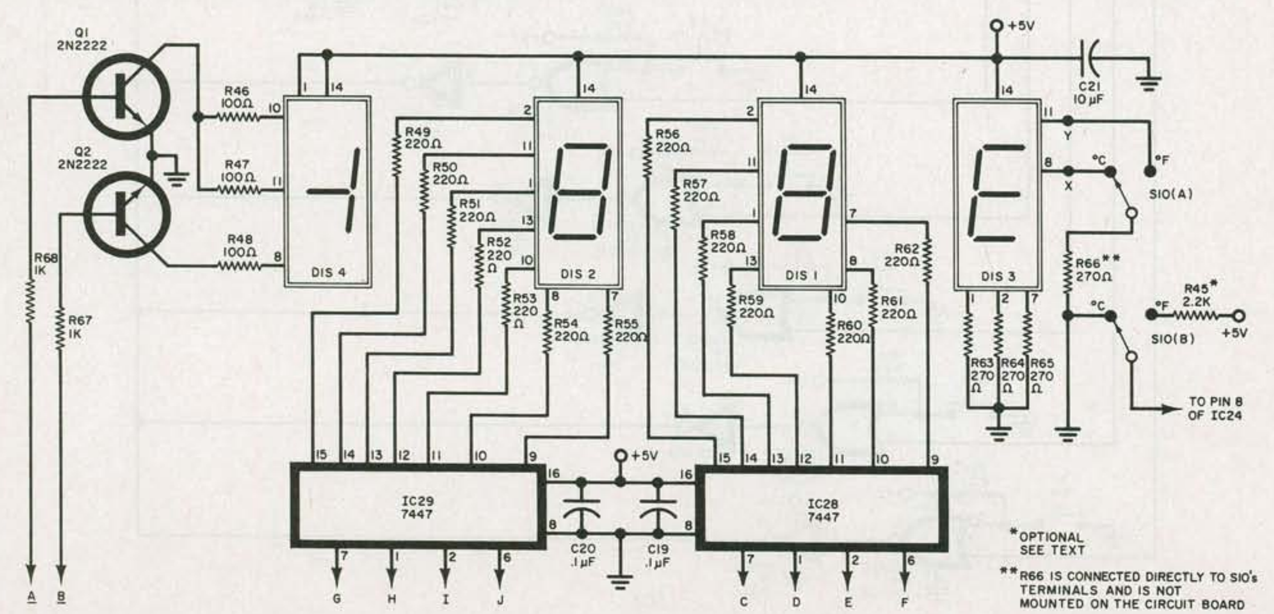


Fig. 4. Schematic of the display circuit.

Schmitt-trigger inverter, *IC2A*, shapes the 60-Hz sine wave into a CMOS compatible signal. These 60-pulses-per-second then go to the clock input of *IC1*, a 14-stage binary ripple counter. Then *IC1*, along with *IC3A*, forms a divide by 14,400 circuit, which results in one pulse every four minutes at its pin 1 output. This short pulse is inverted by *IC2B* and lengthened by *IC4*.

After leaving *IC4*, the pulse is about 50 ms long and is again inverted by *IC2C* before it is applied to the non-maskable interrupt ($\overline{\text{NMI}}$) input of the CPU (pin 6). When this pin goes from high to low, the CPU completes its present instruction and then jumps to a new set of instructions which tell it to find the present temperature and then calculate the mean temperature and degree-days.

This article will be continued next month with instructions for construction, calibration and applications. ◇