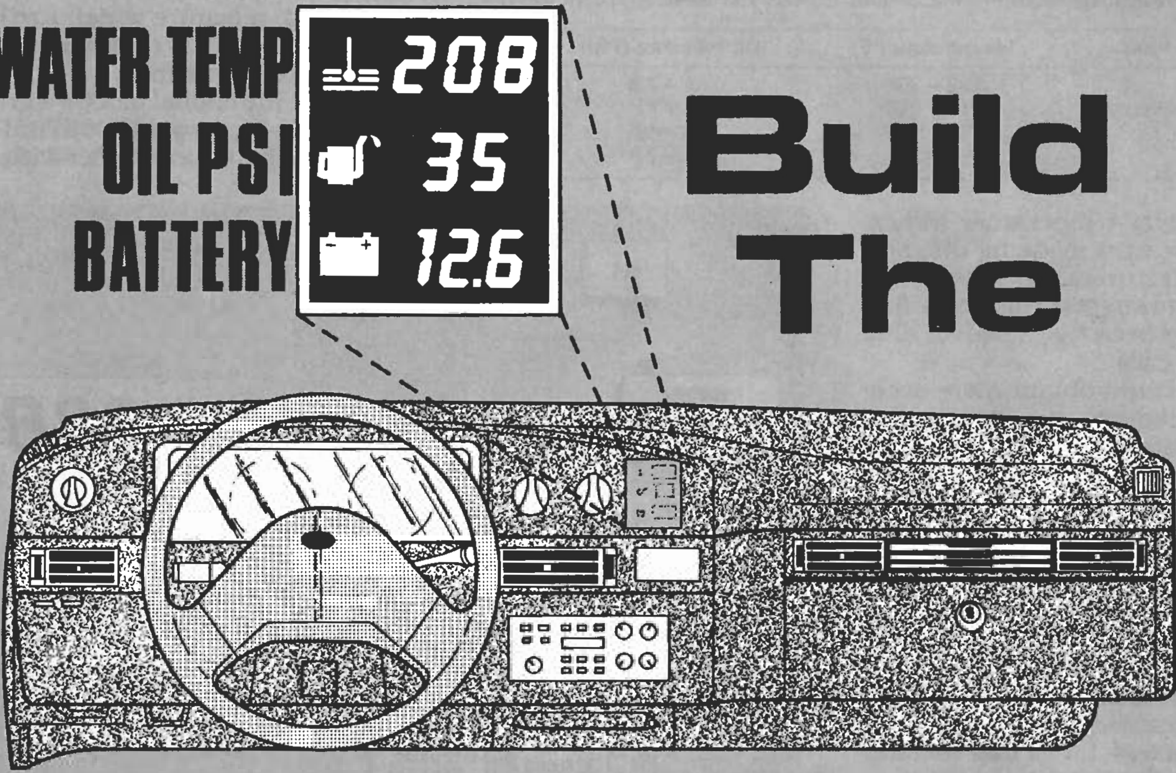
Build The SMARTGAGE



Build this dashboard instrument and get precise readouts of your car's water temperature, oil pressure, and battery voltage.

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MODERN AUTOMOBILE DASHboards have a lot of warning indicator lights, but they don't give you, the driver, much meaningful information. When they light up, they tell you that there is some malfunction; some variable is outside of a vague limit. Unfortunately, when you get that warning, your engine or one of its support systems might already have been damaged. However, that cluster of lights is the only status reporting system that your car has.

Would you like a single miniature instrument on your dashboard that would give you a quantitative readout of water temperature, oil pressure, and battery voltage—not just vague fault indications? Smartgage, the subject of this article, does exactly that.

Smartgage provides a digital readout of the three variables as well as an illuminated icon to indicate the nature of the fault. It supplements rather than replaces the existing instrumentation in your car. Before discussing Smartgage in detail, it is useful to consider the accuracy of the existing status instruments in even the latest cars.

A survey of automobiles made within the last ten years reveals considerable tolerance variation in warning lights. For example, the temperature warning light of a typical General Motors car will not be illuminated until the engine has reached a temperature of between 245°F and 265°F. The tolerance of Ford car indicators was found to be similar.

The low oil pressure indicators installed by the two giant U.S. automakers are equally ineffectual. Ford cars indicate a lubrication problem when oil pressure has dropped to about 5 psi, and the warning light on GM cars turns on only when oil pressure is between 2 and 7psi. Table 1 summarizes the measurement limits for oil pressure

TABLE 1
WARNING LIGHT THRESHOLDS FOR TYPICAL AUTOMOBILES

Manufacturer	Temperature (°F)	Oil Pressure (PSI)	Model Year
Ford	239 – 251	4 – 7.5	1967 – 89
General Motors	245 – 265	2 – 7	1958 – 88
Chrysler	247 – 259	8 – 12	1962 – 82
Foreign	250 – 265	2.5 – 7.5	1962 – 85

and water temperature indicators for cars made by different manufacturers. There is no evidence to suggest that these limits have been tightened on 1992 model cars.

You could obtain more accurate readings if you installed separate electromechanical gauges, but each gauge would be larger than the multifunction Smartgage. Moreover, aftermarket gauges are unsightly and are not compatible with the interior decor of a late-model car.

Smartgage is a compact microcontroller-based system that can monitor and display three parameters. It has user-settable alarms that permit the driver to enter specific "safe-limit" conditions for water temperature, oil pressure, and battery voltage so they can be individually monitored. Smartgage can be installed easily in most vehicles. Measuring only 2 × 2.5 inches, it smaller than a 1-inch stack of business cards.

How Smartgage works

Whenever your car's ignition switch is turned on, Smartgage beeps twice to tell you that it's in working order. First it displays all four alarm settings sequentially so that they can be checked, and then it displays the actual temperature, oil pressure and battery voltage. If a setting is exceeded, the OUT-OF-LIMIT display and annunciator flash, while the IN-LIMIT displays are blanked.

The speaker beeps ten times and then stays quiet for five minutes. During that time, the IN-LIMIT displays are unblanked, while the OUT-OF-LIMIT display continues to flash. At the end of the five-minute interval, the IN-LIMIT displays are again blanked and the speaker beeps ten more times. This cycle will continue until the alarm condition is corrected or readjusted.

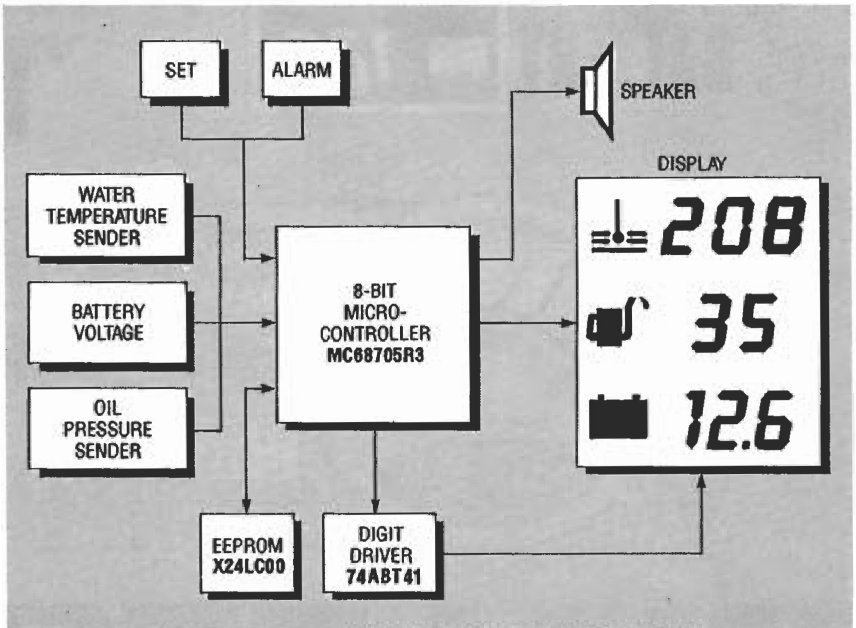

FIG. 1—SIGNALS FROM TRANSDUCERS for water temperature, battery voltage, and oil pressure are processed by the microcontroller for display and alarm.

Whenever the reading returns to an IN-LIMIT value, the alarm condition is reset automatically, and will stop the display from flashing and beeping. The highest alarm priority is given to oil pressure; next are water temperature, low-battery voltage, and finally high-battery voltage.

The alarm settings are stored in nonvolatile EEPROM, and are fetched and displayed sequentially whenever the ignition switch is turned on. Smartgage includes a simple two-button alarm setting sequence.

Smartgage theory

Figure 1 is a functional block diagram for Smartgage. Input signals are supplied to the instrument from standard automotive transducers or *senders* available in most retail automotive parts stores. The inclusion of a software-driven microcontroller permits a low parts count. There are only four integrated circuits: voltage regulator, microcontroller, EEPROM, and display driver. The multidigit, seven-segment LED display modules are multiplexed, a feature which further reduces circuit complexity and component count.

The functional block diagram for the Motorola MC68705R3, an 8-bit microcontroller with an on-chip EPROM, is given in Fig. 2. It has four eight-bit input/output ports permitting it to drive the multidigit LED display modules without external decoder IC's. Ports A, B, and C (clusters of eight pins) are programmable as either input or output lines under software control.

Figure 3 is the schematic for Smartgage. The host vehicle's 12-volt battery provides the raw power, and the regulated 5-volt DC for the IC's is obtained from three- terminal positive voltage regulator IC1. Diodes D1 and D2 protect the circuit against negative voltages at the power input terminal, and capacitors C1 and C2 reduce noise voltages on the input and output sides of IC1.

Power is supplied to microcontroller IC3 at pin 4 (V_{CC}). Electrolytic capacitor C6 is connected to RESET pin 2. Capacitor C6 and a pull-up resistor within IC3 form a reset time-delay circuit. That time delay allows IC3's internal clock signal to stabilize before it begins program execution.

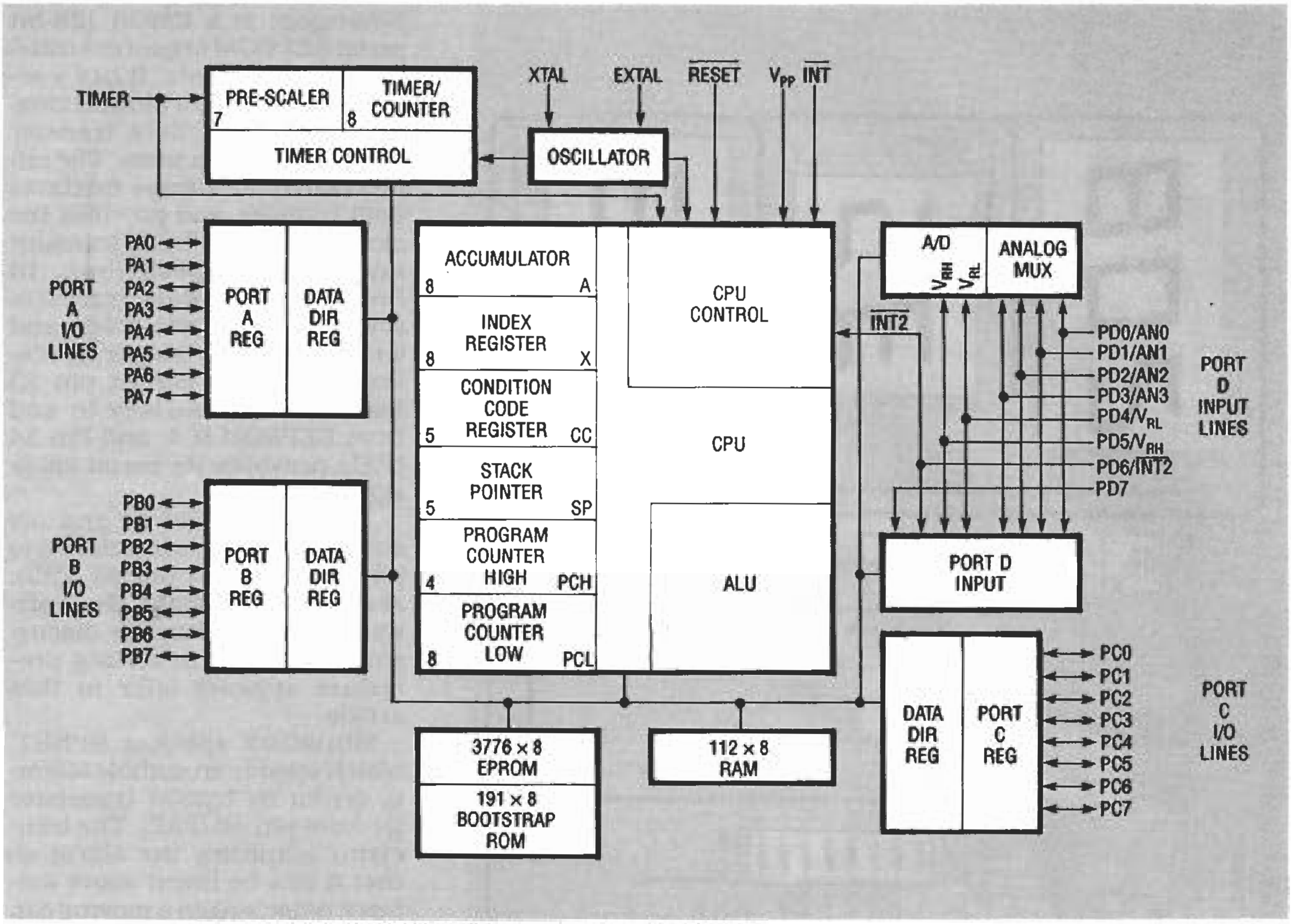

FIG. 2—BLOCK DIAGRAM OF THE MC68705R3 showing how the four ports and control pins are organized.

In Smartgage, Port B drives the segments and decimal points (a through g and d.p.) of the LED digital displays, and port C controls the anodes of the eight digits. Port A is assigned to several alarm function, and EEPROM communications tasks.

Two of the eight port A pins, PA0 (pin 33) and PA1 (pin 34), are assigned to serial data and serial clock for the EEPROM, which stores the alarm settings. Pin PA2 (pin 35) is assigned to ALARM switch S2, and PA3 (pin 36) is assigned to SET switch S1. Pin PA7(pin 40) drives the speaker.

The port D input lines service IC3's internal analog-to- digital converter. Electrolytic capacitor C7 is connected between the two A/D converter reference voltage pins (PD4/V_{RL}) pin 20 and PD5/V_{RL})(pin 19) to reduce any noise voltage.

Control for the on-chip clock oscillator is provided through pin 5 (EXTAL) and pin 6 (XTAL) of IC3. A crystal resistor/capacitor combination or an external signal can be connected to these pins to provide clock pulses. Analog-to-digital conversion in IC3 is performed by successive approximation, so a crystal-controlled timebase is not necessary; an RC oscillator option was selected. A 15 K resistor between pin 6 and pin 4 (V_{CC}) provides an approximate 4-MHz clock frequency.

An important feature of the MC68705R3 for this application is its on-chip multi-channel eight bit A/D converter. It reads analog voltages and converts them to digital values. The converter processes analog input data for three inputs: battery voltage, oil pressure, and water temperature. One digital conversion is made for each analog input every 30 machine cycles.

Refer again to the schematic, Fig. 3. To initiate the alarms connected to Port A, alarm settings must be stored when the car's ignition switch is off. Two options were considered:

- Storing alarm settings in CMOS static RAM and retaining the data in memory with the car battery as a standby power source.
- Installing an EEPROM which does not need standby power.

The CMOS SRAM was the least desirable option because data would be lost if the car battery were disconnected, as would occur if the battery were replaced. By contrast, an EEPROM is ideal because it can store alarm settings without data loss even if Smartgage is removed from the car. Whenever an alarm is set or changed, the new values are written serially to the EEPROM. Therefore, when the Smartgage is powered up, the settings are fetched and stored in the microcontroller's RAM for program execution.

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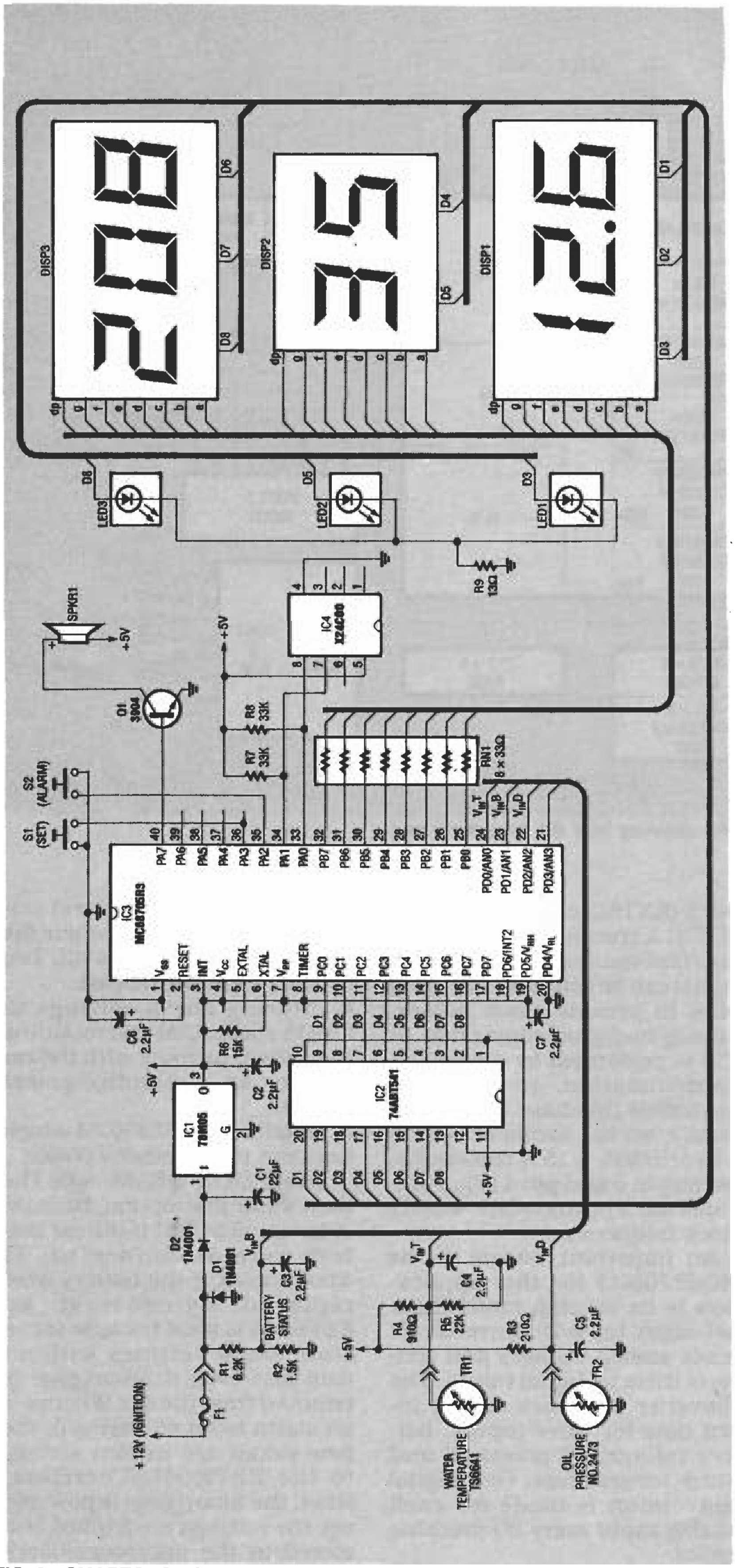


FIG. 3—SMARTGAGE SCHEMATIC. The water temperature and oil pressure senders are equivalent to variable resistors.

Smartgage is a CMOS 128-bit serial EEPROM organized internally as 16 × 8 bits. It has a serial interface and a bidirectional bus permitting data transfer over only two two wires. The microcontroller always initiates data transfer, and provides the clock pulses for both transmit and receive operations. In Smartgage, all data transfers are done with byte reads and writes (eight bytes per operation). As stated earlier, pin 33 transfers data serially to and from EEPROM IC4, and Pin 34 (PA1) provides its serial clock signal.

The ALARM switch S1 and SET switch 2 interrupts (connected to pin 36 (PA3) and pin 35 (PA2), respectively, access the software. A more complete discussion of the alarm-setting procedure appears later in this article.

Miniature speaker SPKR1, which sounds an audible alarm, is driven by bipolar transistor Q1 from pin 40 (PA7). The transistor amplifies the alarm so that it can be heard above ambient noise within a moving car.

As stated earlier, port B pins PB0 to PB7 (pins 25 to 32) drive the segments and decimal points of the LED display modules DISP1, DISP2, and DISP3. A binary word with the desired segment-switching information is stored by IC3's software. Simultaneously, a digit enable pulse for each digit is stored in Port C—PC0 (pin 9) to PC7 (pins 16). These are labeled D1 to D8 in Fig. 3. The multiplexed switching sequence runs through all digits and then repeats itself.

Port B was assigned to switch all of the LED display segments and decimal points because it is the only port capable of sinking necessary 10-milliampere current. Resistor network RN1 contains the series current-limiting resistors needed to switch the segments and decimal points because IC3's input/output ports do not include internal resistors.

Common-anode LED display modules were selected so a worst-case current of only 80 milliamperes will still be able to illuminate all eight segments when a number "8" is displayed. Because a current of that magnitude is not available from IC3, an octal noninverting buffer, IC2, is needed to drive the display module's anodes. The digits are time-division multiplexed by the microcontroller's program.

The annunciator light bars LED1, LED2, and LED3 are turned on sequentially to coincide with display module digits D8, D5 and D3. Thus, only the appropriate icon will be illuminated during the alarm-check, alarm-active, or alarm-setting modes.

Port D, configured as an input only port, supplies input information to the microcontroller's A/D converter. Pin 20 (PD4/V_{RL}) voltage reference low, and pin 19 PD5/V_{RH}) voltage reference high, define the acceptable input voltage limits. Pins 21 through 24 (PD3/AN3 to PD0/AN0) are inputs for the four multiplexed channels of the A/D converter. Pin 17 (PD7) and pin 18 (PD6/INT2) are not used in Smartgage.

Pin 24 (PD0/AN0), designated V_{IN}T, receives an analog input voltage from the temperature sender TR1 on the car's engine. The sender is an NTC (negative temperature coefficient) thermistor in a brass housing. Because the voltage across the sender is inversely proportional to temperature, a software instruction inverts that value before it is used by the program. Smartgage's temperature gauge reads from 0°F to 255°F.

Pin 23 (PD1/AN1), designated V_{IN}B, is the battery voltage input. Battery voltage is scaled by voltage-divider R1-R2. The scale factor is approximately 5:1. Thus, a battery voltage of 13.8 volts DC is reduced to 2.7 volts DC before it reaches the A/D converter. When processed by the software program, that voltage produces an accurate voltage readout on display DISP1. Electrolytic capacitor C3 filters any AC noise present on the battery voltage input pin. The battery voltage readout has a range of 0 to 25 volts DC.

Pin 22 (PD2/AN2), designated V_{IN}D, is connected to the oil pressure sender TR2, a variable resistor. The signal from the oil pressure sender specified in the Parts List is directly proportional to pressure.

Software explained

Software gives Smartgage its ability to multiplex the analog-to-digital inputs, perform binary to BCD (binary- coded decimal) conversion, and do display scanning as well as alarm servicing. It also makes it possible to monitor three independant gauges with a single compact instrument.

The main program flow chart is shown in Fig. 4. The program begins at POWER-ON RESET with initialization. The alarm settings, which are stored in the EEPROM, are fetched and written to microcontroller IC3's RAM memory. The program then multiplexes through the A/D inputs: temperature, oil pressure, and battery voltage. The analog voltages are converted to binary numbers by IC3's on-chip A/D converter and stored in the assigned memory locations.

The binary to BCD conversion subroutine is then called, and the stored binary numbers are converted to BCD. The converted numbers are then stored in a different memory location where they will be fetched by the display scanning subroutine of the program. In this section of the program, a timer interrupts to multiplex the display and update the eight digits individually and sequen-

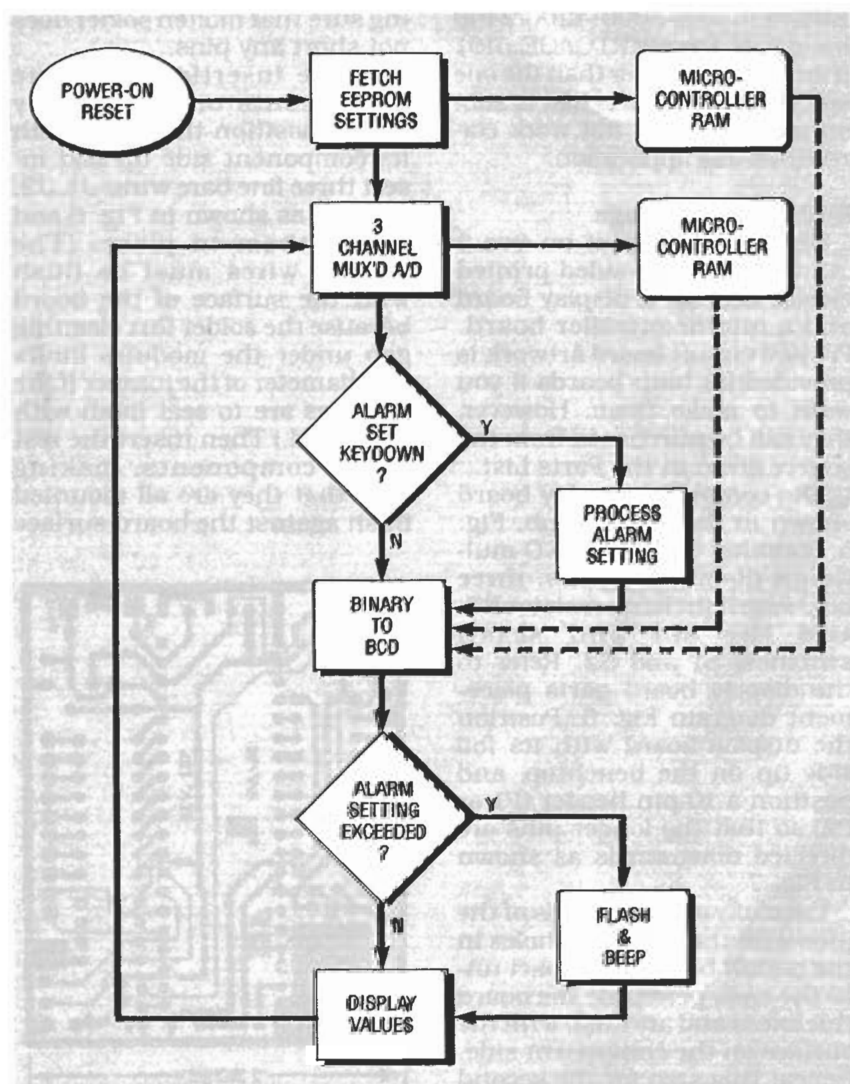


FIG. 4—MAIN PROGRAM FLOWCHART FOR SMARTGAGE showing the decision loops.

tially with new segment data about every 1.6 milliseconds. (The entire display is updated every 13 milliseconds.).

Alarm switch S2 is checked regularly during program execution to determine if an alarm setting condition has been set. If it has, the alarm setting subroutine is called. If any settings are changed, EEPROM IC4 is updated with the new values when the program exits the subroutine. The alarm settings that are fetched from IC4 at the start of the program are constantly compared with the values read from the sender to determine if an alarm condition has ocurred.

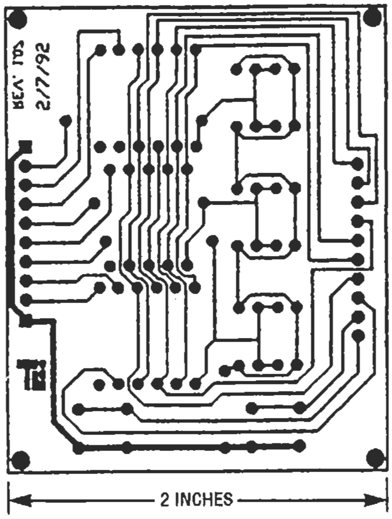
The Smartgage firmware in the Motorola 5-record format is available from the address given in the Parts List or from the R-E BBS (526-293-3000; 1200/2400 baud 8, N, I as SMRTGAGE.519). If an EEPROM other than the one specified in the Parts List is substituted, it might not work correctly in this application.

Building Smartgage

Smartgage is built on two 2 × 2.5-inch single-sided printed circuit boards: a display board and a microcontroller board. Printed circuit board artwork is provided for both boards if you want to make them. However, they can be purchased from the source given in the Parts List.

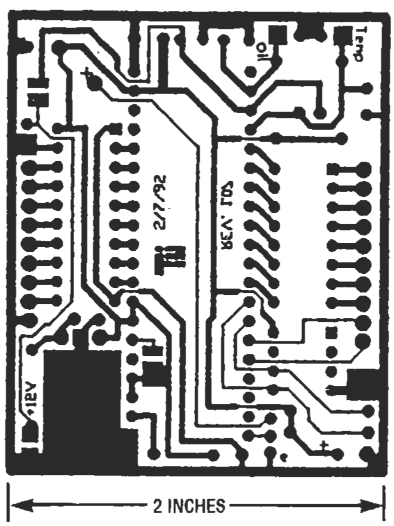
The completed display board shown in the photograph, Fig. 5, contains the three LED multidigit display modules, three LED icon light bars, resistor R7, and the SET and ALARM switches, S1 and S2. Refer to the display board parts placement diagram Fig. 6. Position the display board with its foil side up on the benchtop, and position a 10-pin header (P1 or P2) so that the longer pins are directed downwards as shown in Fig. 7.

Carefully align the ends of the pins with the matching holes in the circuit board, and inset until the ends penetrate the board thickness and are flush with the surface on the component side. Repeat this step for the second header. Now reverse the board and solder the two end pins of each header with a low-heat soldering pencil. Then solder the rest of the pins carefully, making sure that molten solder does not short any pins.



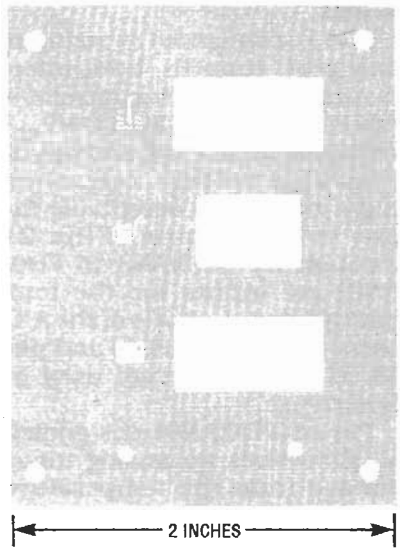
FOIL PATTERN FOR DISPLAY BOARD.

Before inserting any more components on the display board, position the board with its component side up and insert three fine bare wires J1, J2, and J3, as shown in Fig. 6 and solder them in place. (The jumper wires must be flush with the surface of the board because the solder flux cleaning gap under the modules limits the diameter of the jumper if the modules are to seat flush with the board.) Then insert the rest of the components, making sure that they are all mounted flush against the board surface before soldering them in place.



FOIL PATTERN FOR MICROCONTROLLER BOARD.

Figure 8 is photograph of the completed microcontroller board. Refer to parts placement diagram Fig. 9 for the installation of components on that board. Start by soldering the surface-mount resistors (SMT) R1, R2, and R6 on the foil side of the board first. (Use fine tweezers to hold the chip resistors in place while you solder them). Use a low-heat soldering pencil with a fine tip and fine guage solder wire. Only a small amount of solder is needed on each end of the chip resistors.



DISPLAY MASK showing the three icons and windows for LED display modules.

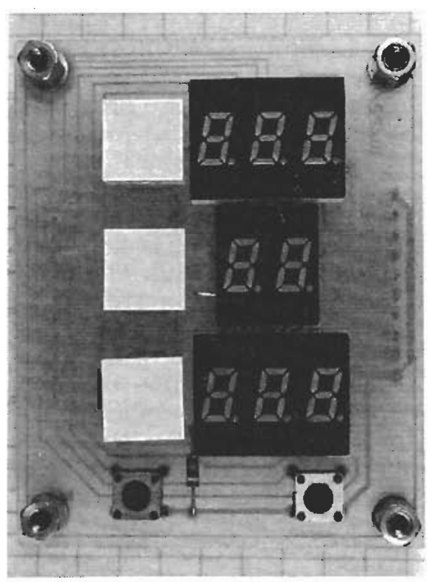
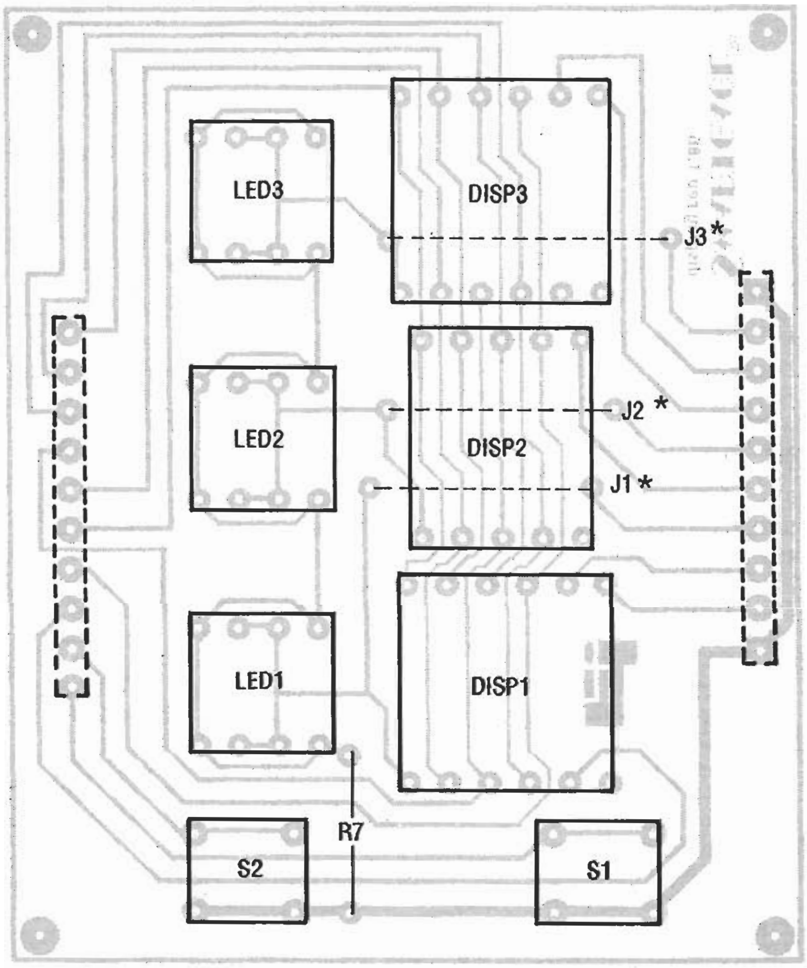


FIG. 5—DISPLAY CIRCUIT BOARD showing the three seven-segment LED display modules and three LED light bars (white squares at left).



* BARE WIRES ON COMPONENT SIDE

FIG. 6—PARTS PLACEMENT DIAGRAM for the display board.

Turn the board over, and insert the axial-leaded resistors and diodes first, making sure that each diode's polarity markings are observed. Next, insert the radial-leaded capacitors and transistor, making sure that their pins are oriented correctly before soldering all parts to the circuit board. Be sure that all of the parts on the component side of the board are installed so that highest surfaces are less than ⅜-inch above the board. Note: Figure 8 shows the three radial-leaded tantalum dipped resistors that were in the prototype, but these are replaced by the miniature aluminum electrolytic capacitors listed in the Parts List.

Insert voltage regulator IC1 so its three pins are positioned in the correct holes in the board and its heat sink is flush with the board. Fasten the sink to the board with a No. 4-40 machine screw, lock washer, and nut through the punched holes in both sink and board. Insert IC2 and IC4 and resistor network RN1, observing their pin 1 positions. Solder all pins.

Insert and solder speaker SPKR1 last. For correct phasing and maximum speaker volume, observe the correct polarity. The plus indicator on the bottom of the speaker should be connected to Q1's collector—*not* to +5 volts. Finally, insert microcontroller IC3 in its socket. Carefully examine the completed circuit board for solder shorts, and check to see that all components have been installed correctly.

Cut a length of colored 0.050-pitch flat ribbon cable with 28 AWG conductors long enough to extend from the intended location of Smartgage on your dashboard, through the firewall to the senders on your car's engine block. With a razor knife, carefully slit the end of the cable to remove a ribbon of four connected conductors. (The colors selected are not important as long as you make note of the color of each wire and its intended function.)

In the prototype, a yellow wire was selected for water temperature, an orange wire for oil pressure, a red wire for 12-volt DC source, and brown wire for ground. This code is used in the remainder of this article and in all figures.

Strip both ends of all wires approximately ¼-inch, and wrap the yellow, orange, and red wire ends around projecting leads at the locations shown in Fig. 9, and solder them in position. The brown ground wire can be secured to the board by loosening the bolt and nut on the heat sink of voltage regulator ICI, wrapping the bare end of the wire around the screw, and tightening the screw. Now trim any excess lead lengths.

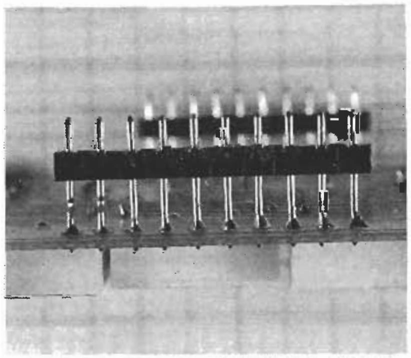


FIG. 7—TEN-PIN HEADERS ARE INSERTED so longer pins enter the foil side and are flush with the component side of the display board.

A fuse holder with fuse should be inserted in the red wire between the microcontroller board and the battery power source. This can be done by carefully splitting out the red