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BUILD THE SMARTBOX

Increase fuel economy while improving your vehicle's performance

Operating the air conditioner in a vehicle is not free. It takes precious fuel to provide the horsepower that is demanded by the A/C compressor. Automotive manufacturers have helped reduce that demand by using a clutch system that allows the compressor to operate only when needed. In such systems, the A/C clutch is controlled by a pressure switch or thermostat that responds to the cooling needs of the passenger compartment.

In addition, the poorest fuel economy always occurs when the vehicle is accelerating or climbing a grade. On the other hand, very little fuel is used during coasting or braking. In fact, when the brakes are applied, the vehicle's kinetic energy—created by the engine to begin with—is purposely turned into heat and wasted. That acceleration/de-celeration sequence is repeated as the vehicle is driven.

Consider this: The load of the air-conditioning compressor is actually a benefit when decelerating and braking, since it helps stop the vehicle. At other times, it is an additional load on the engine, using extra fuel. Therefore, if the air conditioning compressor could be somehow turned off during heavy accelerating and allowed to run when needed the rest of the time, less fuel would be used to operate the A/C system.

The Smartbox described here helps synchronize the compressor with the load demand on the engine, so that the compressor is off when accelerating, and on when coasting or braking. When the Smartbox allows compressor operation, the A/C system is under its normal pressure switch/thermostat control. Without the added load of an A/C compressor when the engine is working extra hard, the Smartbox will save fuel.

An additional benefit provided by the Smartbox is to improve vehicle performance by temporarily disabling the compressor during acceler-

ation. With the compressor off, all available horsepower can be used to increase vehicle speed. That can be an important safety feature.

The Smartbox, contained on a small printed-circuit board, is easily connected to the wiring system of any vehicle. It is completely automatic in operation and never needs attention. The only operating control is an override switch that allows the driver of the vehicle to disable the Smartbox and return the A/C system back to its normal, unsynchronized operation. A pair of light-emitting diodes let you see what the Smartbox is doing at all times.

How it Works. The intake manifold of gasoline engines is always under a partial vacuum. Vacuum is sometimes expressed in inches of mercury, where a perfect vacuum is equal to about 30 inches. The level of vacuum produced in a gasoline-powered engine is always less than 30 inches, and varies with the load on the engine.

When idling, a gasoline engine will produce between 15 and 22 inches of vacuum. When the vehicle is cruising on a level roadway, the vacuum decreases to about 10 to 18 inches. When accelerating or climbing a hill, engine vacuum falls to less than 10 inches of mercury and can be close to zero during full-throttle conditions. The variation of engine vacuum can be used to directly measure how hard the engine is working. A special sensor is used by the circuit to measure engine vacuum, and that enables the Smartbox to determine under what conditions the vehicle is being driven.

About the Circuit. The schematic diagram for the Smartbox is shown in Fig. 1. The circuit is powered by a 12-volt source that is active only when the ignition of the vehicle is turned on. In that way, the Smartbox will not drain battery current when the vehicle is not being driven. Protection from voltage transients is provided by D1, R1, and C1. The supply voltage is regulated to 9 volts by IC1 for the remainder of the circuit. The Smartbox shows that the regulator is working by lighting LED1.

The heart of the Smartbox is SEN1, a modern solid-state differential-pressure sensor. That sensor is made up of a silicon substrate to which a set of piezo-resistors is attached. Those resistors are designed to change value if the substrate is stressed or bent in any way.

The silicon substrate creates two chambers. A port for each chamber lets positive or negative differences in pressure be measured by

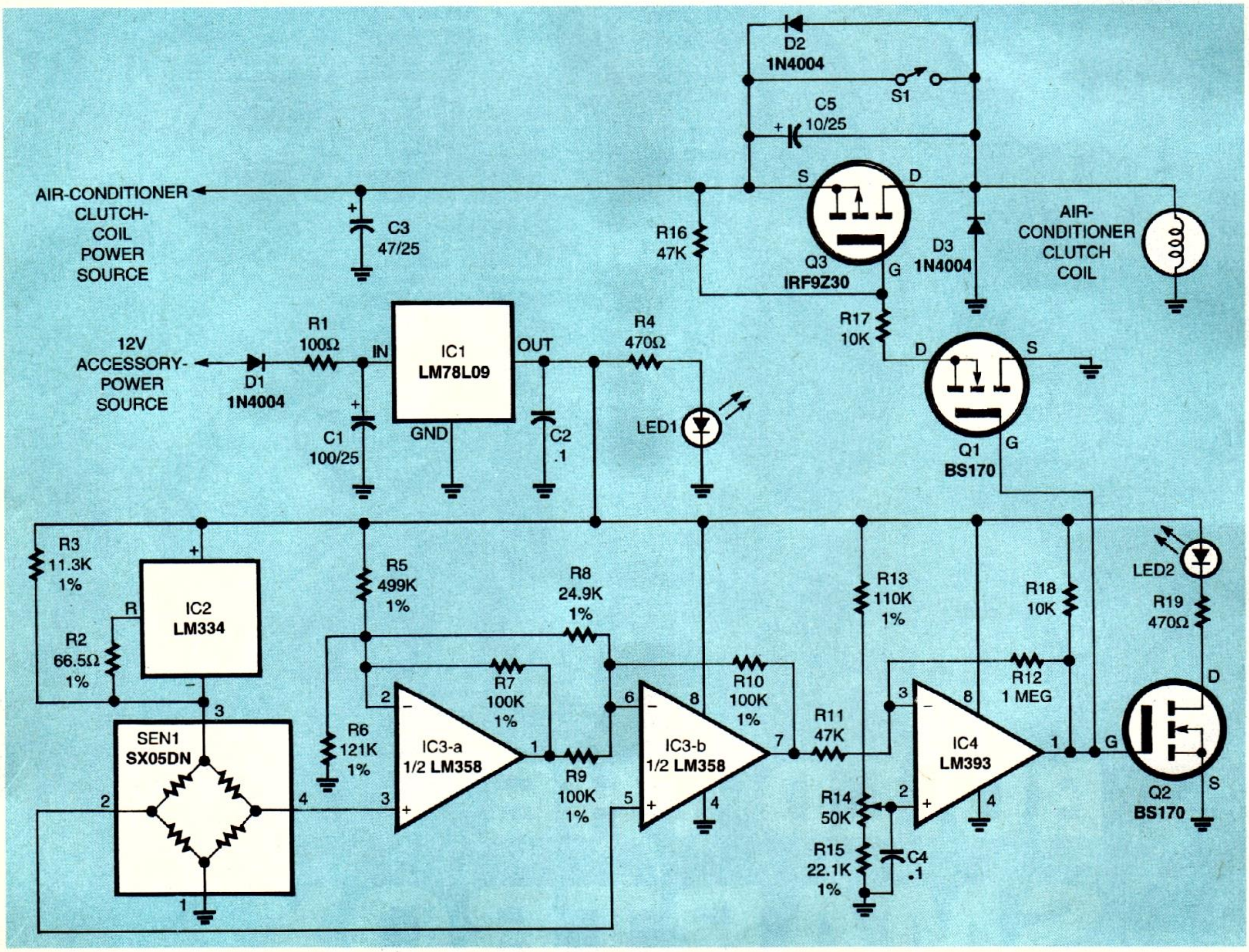


Fig. 1. The Smartbox senses when an automobile's engine is working hard, and cuts out the air-conditioner compressor to improve performance and save money. Using metal-film resistors makes the circuit stable over a wide temperature range.

the sensor. For the Smartbox, one port is exposed to the atmosphere as a reference, and the other is connected to the engine's intake manifold by means of a rubber hose. That lets the sensor respond to variations in engine vacuum.

The resistors within the sensor are wired together in a Wheatstone-bridge configuration. The values of the resistors are such that the bridge is balanced when no stress is placed upon the substrate. Any pressure difference between the two chambers of the sensor caused by engine vacuum will result in mechanical stress being placed upon the substrate, and thus produce a predictable amount of bridge unbalance.

configured as a differential amplifier with a gain of 10. The gain is set by resistors R5–R10. A 1.8-volt offset is created by R5 and R6. That offset voltage is added to the sensor voltage. Thus, the output voltage of the amplifier, measured at pin 7 of IC3, is at 2.7 volts during normal cruising conditions. That voltage represents the load on the engine, and will vary with throttle position.

The output of IC3-b is connected to the positive input to IC4, a voltage comparator. The negative input of IC4 is set to a reference voltage by R13, potentiometer R14, and R15. The use of potentiometer R14 lets the Smartbox be calibrated to any particular vehicle for the best balance between economy and

of Q3 is driven by the compressor-clutch feed wire, and the drain terminal is connected to the clutch coil. As IC4 switches back and forth between 0 and 9 volts, the A/C compressor of the vehicle will be under control of the Smartbox as indicated by LED2. However, under cruising conditions, the compressor will still cycle in accordance with the A/C system's pressure switch/thermostatic control.

During a sustained hill-climb or when starting the vehicle after it has been parked in full sunlight, it might be desirable to have full-compressor operation. An override switch, S1, has been provided to allow the A/C system to generate full cooling power regardless of engine operating conditions.

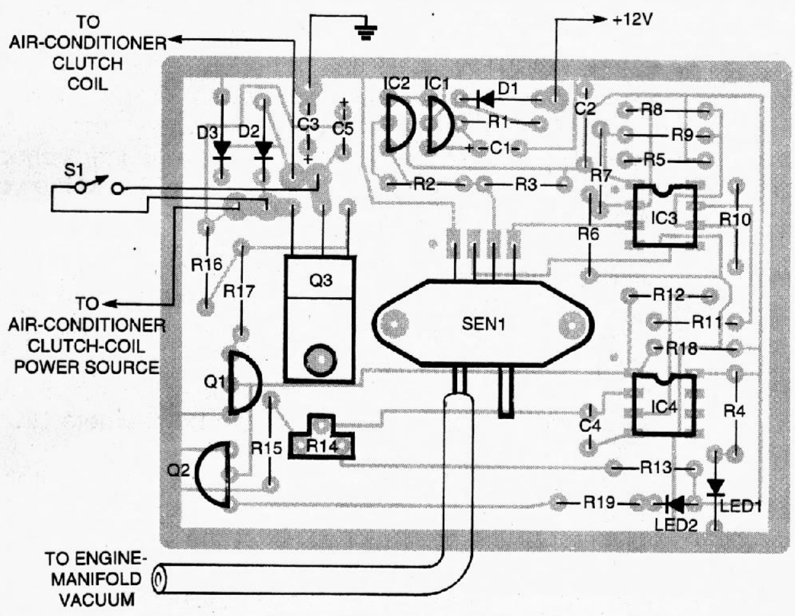


Fig. 2. Use this parts-placement diagram when building the Smartbox. Pay close attention to the orientation of polarized components, especially SEN1.

The sensor resistors are driven by a temperature-compensating constant-current source provided by IC2, R2, and R3. The differential output of the sensor, measured between terminals 2 and 4, will be 90 millivolts or more during normal cruising conditions. When the engine is called upon to deliver more power, the voltage will drop below 90 millivolts as determined by the throttle setting and load on the engine.

The output of SEN1 is amplified by IC3. The two sections of IC3 are

performance. Since the output voltage at pin 7 of IC3-b will decrease as engine load increases, R14 can be set to the neutral point between cruising and accelerating.

When the Smartbox calls for compressor operation, the output of IC4 will be about 9 volts. That turns on Q1, which in turn activates Q3 through voltage divider R16 and R17. At the same time, Q2 is activated, illuminating LED2.

The Smartbox turns the compressor on and off with Q3, a P-channel power MOSFET. The source terminal

Construction. The Smartbox circuit is not critical and may be hard-wired on a perfboard using good construction techniques. Alternatively, a foil pattern for a single-sided PC board is provided. If desired, an etched and drilled PC board is available from the source given in the Parts List.

If you use a PC board from the foil pattern or from the source given in the Parts List, follow the parts-placement diagram in Fig. 2 for component location.

For maximum reliability under the various conditions of vibration present in a vehicle, it is recommended that the integrated circuits be soldered directly to the circuit board. Be sure to install all polarized components with the correct orientation. One part placed backwards in the circuit will prevent the Smartbox from working and could cause damage to one or more components.

For circuit accuracy and stability be sure to use metal-film resistors where specified in the Parts List. Ordinary carbon resistors are not temperature stable and should not be used in place of metal-film types.

Although Q3 is a power transistor that will handle the current for the A/C clutch, it operates relatively cool so no heat sink is required. It should be mounted to the board with a machine screw and nut.

The pressure sensor is mounted

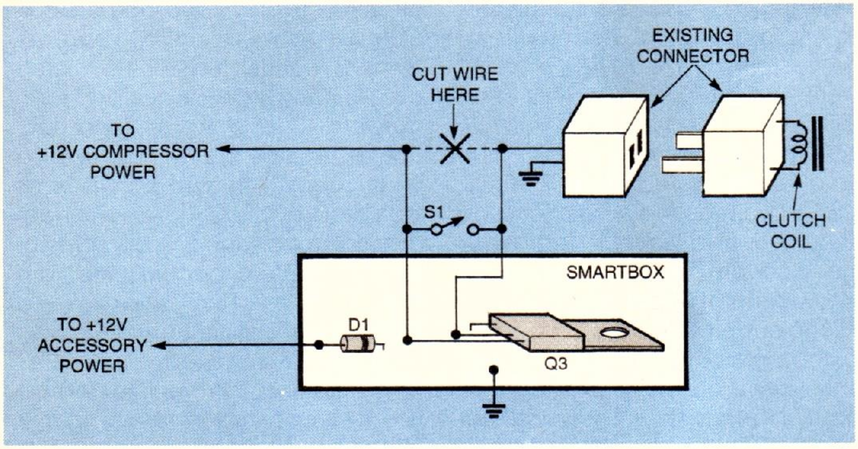


Fig. 3. Here's a typical Smartbox installation. Double-check the voltage polarities of the clutch-coil wire. If your vehicle supplies power to the clutch and turns the ground on and off, the wires to the Smartbox will have to be reversed. Hooking up the clutch wires backwards will destroy D2 and possibly Q3.

directly on the board. Care should be taken when handling the pressure sensor. Note the location of pin 1, which is designated by a small dot printed on its housing. Once the proper orientation of SEN1 is determined, bend the four leads gently, so that they are at right angles with the body of the part. Avoid placing stress on the terminals where they enter the housing. Use suitable hardware or RTV silicone-rubber adhesive to secure the sensor to the board. If screws are used to mount SEN1, do not overtighten them. Excessive stress on the sensor's plastic case might cause it to crack, destroying the sensor.

Four connecting wires are required, which should be no smaller than 16-gauge insulated stranded wire. Use different colors if possible to help avoid wiring errors. Be sure to allow sufficient lead length for the two clutch wires, which must pass through the firewall to the engine compartment of the vehicle.

When the printed circuit board is completed, examine it very carefully for opens, short circuits, and bad solder connections that might appear as dull blobs of solder. Any solder joint that is suspect should be redone by removing the old solder with desoldering braid, cleaning the joint, and carefully applying new solder. It is far easier to correct any possible problems at this stage rather than later if you discover that the Smartbox does not work.

The printed-circuit board should be placed into a small enclosure for protection against dust and dirt. Drill holes in the enclosure for connecting wires, vacuum tubing, LEDs, and the override switch. Mount the board in the enclosure using suitable hardware. Do not install the Smartbox in the vehicle until instructed to do so later, after the checkout procedure is completed.

Checkout. To perform the checkout procedure, a well-filtered 12-volt DC power source is required, as well as a DVM or VOM. A common 12-volt automotive lamp such as a #1157 may be used to simulate the clutch load. The DC supply must be able to handle the lamp current, which is about 3 amps. Check the lamp with the power supply, before starting, to be sure that they both work.

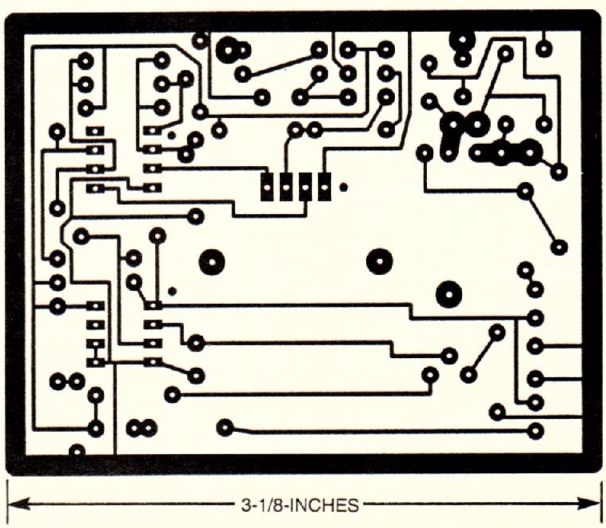
Connect the test lamp to the clutch wire of the circuit (drain of Q3), and circuit common. Apply 12-volt power to the accessory lead (anode of D1), and the clutch-power lead (source of Q3). Be sure to observe proper polarity. The voltage at the output terminal of IC1 should be 9 volts, and LED1 should be illuminated.

If the 9-volt reading is either too high or low, or the LED is not illuminated, remove power. Troubleshoot the circuit and correct the fault before proceeding with the checkout. Check the orientation of D1, C1, C2, C3, LED1, IC1, IC2, IC3, and IC4. Measure the resistance between the 9-volt power bus and circuit common to be sure there is no short circuit.

Once the supply voltage is correct, measure the voltage at pin 3 of SEN1. The reading should be about 6 volts. If it is incorrect, check the orientation of IC2, and the values of R2 and R3.

With the 9-volt regulator and IC2 operating properly, adjust R14 over its range and verify that LED2 and the test lamp are illuminated over part of the adjustment range, and extinguished over the remainder. Set R14 to the point where LED 2 and the lamp just go off.

Now take a length of suitably sized rubber tubing and carefully place it over the vacuum sensing



Here's the foil pattern for the Smartbox. The circuit is simple enough to fit onto a single-sided PC board.

PARTS LIST FOR THE SMARTBOX

SEMICONDUCTORS

IC1—LM78L09 voltage regulator, integrated circuit
IC2—LM334Z constant-current regulator, integrated circuit
IC3—LM358N dual op-amp, integrated circuit
IC4—LM393N dual comparator, integrated circuit
D1–D3—1N4004 silicon diode
LED1, LED2—Light-emitting diode, red
Q1, Q2—BS170 N-channel MOSFET transistor
Q3—IRF9Z30 P-channel MOSFET transistor

RESISTORS

(All resistors are ¼-watt, 1% metal-film units, unless otherwise noted.)
R1—100-ohm, ¼-watt, carbon-composition
R2—66.5-ohm
R3—11,300-ohm
R4, R19—470-ohm, ¼-watt, carbon-composition
R5—499,000-ohm
R6—121,000-ohm
R7, R9, R10—100,000-ohm
R8—24,900-ohm
R11, R16—47,000-ohm, ¼-watt, carbon-composition
R12—1-megohm, ¼-watt, carbon-composition
R13—110,000-ohm
R14—50,000-ohm potentiometer
R15—22,100-ohm
R17, R18—10,000-ohm, ¼-watt, carbon-composition

CAPACITORS

C1—100-µF, 25-WVDC, electrolytic
C2, C4—0.1-µF, ceramic-disc
C3—47-µF, 25-WVDC, electrolytic
C5—10-µF, 25-WVDC, electrolytic

ADDITIONAL PARTS AND MATERIALS

S1—SPST toggle switch
SEN1—SX05DN differential pressure sensor (SenSym)
Enclosure, hookup wire, rubber vacuum tubing, etc.

Note: The following items are available from: A. Caristi, 69 White Pond Road, Waldwick, NJ 07463: Etched and drilled PC board, $9.50; SEN1, $38.75; IC1, $2.00; IC2, $5.75; IC3, $2.00; IC4, $2.00; Q1, $2.00; Q2, $2.00; Q3, $7.75. Please add $5.00 postage/handling. SEN1 is also available from: SenSym, 1804 McCarthy Blvd., Milpitas, CA 95035, Tel: (408) 954-1100.

port of the pressure sensor as indicated in Fig. 2. Apply suction to the open end of the tubing with your mouth and note that it is possible to cause LED2 and the test lamp to light. If they remain lighted when the vacuum is removed from the tubing, gently apply pressure to the tubing to cause the LED and lamp to become extinguished again.

If you obtain the results outlined above, the checkout procedure is completed. If the circuit is not operational, verify that the tubing is attached to the vacuum port of the sensor. The voltage at pin 7 of IC3 should normally be about 1.8 volts, and should increase as vacuum is applied to the sensor. If it does not, check IC3 and all components associated with it.

If the sensor and IC3 are operating correctly, check the output voltage of IC4. It should switch between 9 volts and 0 as R14 is adjusted over its range. If that does not happen, check the orientation of Q1, Q2, D2, D3, and LED2. The values of R16 and R17 should also be checked. If everything else checks out, the transistors might need to be replaced.

Check the voltage at pin 2 of IC4 as R14 is rotated over its range to verify that it can be set both above and below the voltage at pin 7 of IC3. If not, check R13, R14, and R15. When pin 1 of IC4 switches to 9 volts, the test lamp is energized through Q1 and Q3, and LED 2 is activated by Q2.

Installation and Final Adjustment. One final adjustment needs to be made before the Smartbox is permanently mounted in the vehicle. A typical installation in Fig. 3 shows how the Smartbox is connected to the electrical system of a vehicle. You must locate the cable harness that feeds the compressor-clutch coil, and a 12-volt accessory wire located anywhere in the vehicle.

To make the final calibrating adjustment, connect the 12-volt accessory lead (anode of D1) to any wire that is powered only when the ignition of the vehicle is turned on. Such a wire can be identified by using a DC voltmeter to verify power as the ignition switch is turned to the on position. Possible choices are connections to the radio, windshield-wiper motor, or A/C-blower circuit.

The ground lead from the Smartbox can be connected to any metal part of the vehicle. You can either use an existing screw (cleaning the metal parts thoroughly) or drill a hole for a no. 8 sheet-metal screw. The remaining two wires of the Smartbox are fed through the firewall into the engine compartment.

Locate the power-feed cable to the compressor clutch, which usually has a two-wire connector that is plugged into the compressor assembly. One of the wires is ground and the other is the power feed. Cut only the power feed line at a convenient location. The insulation on each cut end is to be stripped back about ³/₈-inch. Identify those ends as "power feed" and "clutch."

Connect the wire from the source of Q3 to the power-feed wire. The connection should be soldered and taped securely. The remaining wire from the connector is tied to the drain of Q3. Again, solder and insulate the connection carefully with electrical tape.

The last connection to Smartbox is the vacuum tubing. Find a source of raw engine vacuum that is not regulated in any way, such as the input side of the vacuum storage container for the heater/air-conditioning controls. Since today's vehicles have a multitude of vacuum-hose connections, you may wish to consult a chassis manual or your local auto mechanic to identify the proper vacuum source. Cut the line squarely at a convenient location, insert a "tee"-type hose splice, and attach the Smartbox's vacuum tubing to the third connection.

The final adjustment of R14 must be made under actual driving conditions with the A/C operating and the blower at high speed. That is best done on a warm or hot day. Choose a level stretch of highway for the adjustment procedure. For obvious safety reasons, an assistant should drive the vehicle as you calibrate the circuit.

Bring the vehicle up to a steady 55 MPH and adjust R14 so that LED2

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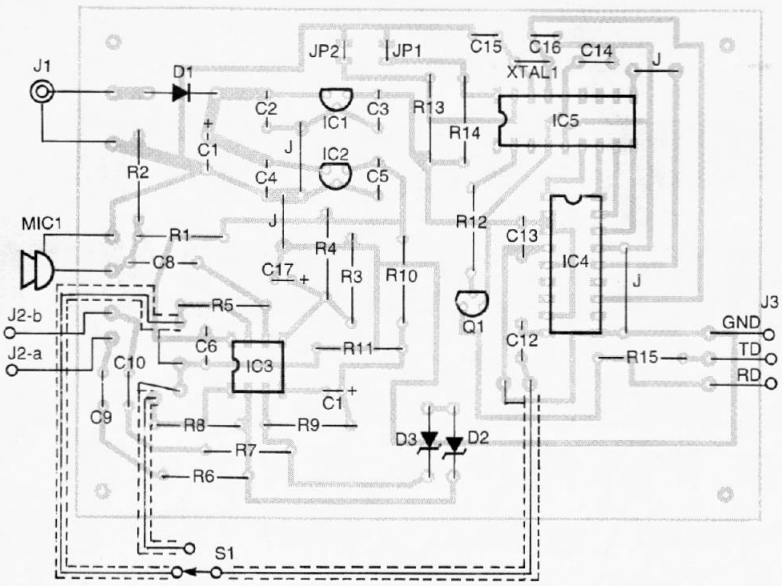
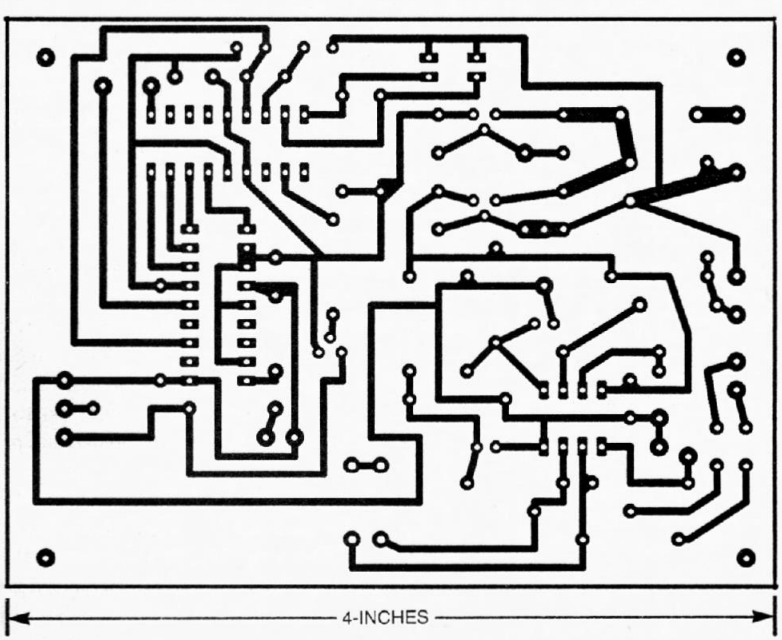


Fig. 2. Use this parts-placement diagram to locate the parts of the DTMF-Plus if you use the foil pattern. Shielded cable should be used to connect S1. The shield should be connected to the ground holes in the PC board only—do not connect them together at the switch.

telephone system will not have any adverse affect on the unit.

Using the DTMF-Plus. Data from the DTMF-Plus can be displayed on a PC using any available communications program. An optional data-logging program is also available from the source given in the Parts List to permanently store any information that is decoded. That program lets you store any data that is decoded for viewing at a more convenient time. For example, you can leave the DTMF-Plus connected to a telephone line and a PC. Each time a number is dialed, it will be stored in the computer for later viewing. Each time the DTMF-Plus sends a carriage return/line feed combination, the line of digits is stored as a call record in a database. Records can be deleted from the database on an individual basis or all records can be deleted at once. That DOS-based program runs on any IBM-compatible computer.

As you explore the abilities of the DTMF-Plus, you'll find new ways to use the unit. One use is as a tester for telephones, modems, and communication programs. The only limit is your imagination. Ω



Here's the foil pattern for the DTMF-Plus. A simple circuit and a few jumper wires easily fit the entire project onto a single-sided board.

SMARTBOX

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just comes on. Then accelerate slightly and note that LED2 goes out. Allow the vehicle to coast, and note that LED2 comes on again.

You will probably wish to drive several miles at various speeds and through upgrades and downgrades to learn how the setting of R14 suits your vehicle and driving habits. It may be readjusted in accordance with individual taste. Remember, when LED2 is on, the compressor is enabled when the air-conditioning system calls for cooling.

Once the calibration is completed to your satisfaction, install the Smartbox in the vehicle where the driver can operate S1 and view the LEDs.

When the vehicle is parked in full sun on a hot day, you may wish to use the override switch to obtain maximum cooling power until the interior is cool. That allows the system to operate normally without the fuel-saving feature. Once the interior of the vehicle is comfortable, switch back to automatic control for improved fuel economy and vehicle performance. Ω