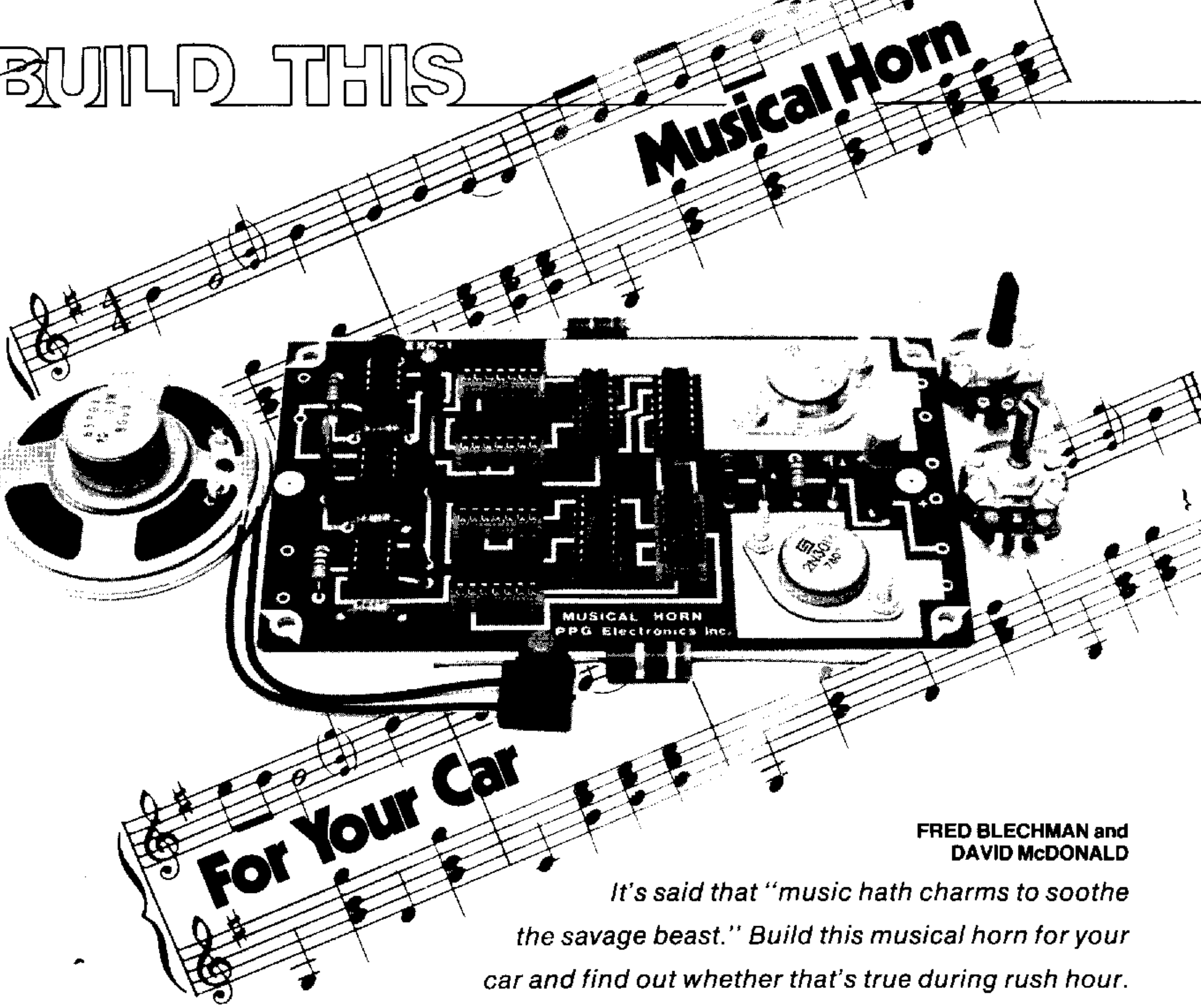
BUILD THIS



Musical Horn For Your Car

FRED BLECHMAN and
DAVID McDONALD

It's said that "music hath charms to soothe the savage beast." Build this musical horn for your car and find out whether that's true during rush hour.

THE FIRST AUTOMOBILES, TRAVELING AT the breathtaking speed of 15 miles per hour, used warning horns operated by squeezing a large rubber bulb to force air through an orifice. As the car evolved so did the horn, going through the "aah-oog-aah" mechanical contraption to the standard electronically-operated-diaphragm horn that has been in use for years. Now you can move into the space age by building your own electronic musical horn for under $35.

The Musical Horn is designed for 12-volt vehicles and uses digital integrated circuits and programmable read-only memories (PROM's) to generate virtually any desired tune, depending on the PROM's installed. Pre-programmed PROM's are available for several tunes (see parts list). The popular "La Cucaracha" is described in detail here.

How it works

You don't have to understand how the Musical Horn works to use it. The discussion that follows is expressed in lay terms for the electronics-oriented non-musician, to describe how the digital circuitry creates the musical notes.

Music is composed of sound of specifically related frequencies (notes) that are sustained for particular durations (beats). Consequently, if we can generate those frequencies in proper relationship to each other, and provide a means to control their duration, we can make music!

The musical scale

There are several different musical scales (tone-series with specific frequency relationships) in use throughout the world. In the United States, the standard scale is the Equally Tempered Chromatic Scale, using the American Standard pitch of A=440 Hz. By definition, the frequency of each note is exactly $2^{1/12}$ (two-raised-to-the-$^{1}/_{12}$th-power or 1.0594631) times the preceding note. This is most easily shown on a piano keyboard, a section of which is illustrated in Fig. 1 with the frequency of each key. The circled numbers are reference numbers for use later.

Our challenge is to generate electronically a range of specifically related frequencies. Obviously, separate oscillators could be used—a very expensive and complicated approach. Or, we could have a single master oscillator and provide numerous "taps"—using resistors or capacitors—to generate each note. That approach is used in many inexpensive toy electronic organs. We're going to do it digitally, though... and without a keyboard.

The approach used here is shown in block-diagram form in Fig. 2. Twelve-volt car-battery power is regulated to supply 5-volts to all IC's. A variable low-speed clock triggers an 8-bit up-counter that is initially set to zero when power is applied. The counter's binary output sequentially addresses a 256-location "song" PROM. Each location contains a 4-bit binary code that defines which of 16 possible notes should be generated at that moment.

The 4-bit binary code that appears on the output of this PROM is the "note command" code, and is directed to one set of inputs of a data comparator. Meanwhile, a variable high-speed clock strobes another 8-bit up-counter whose

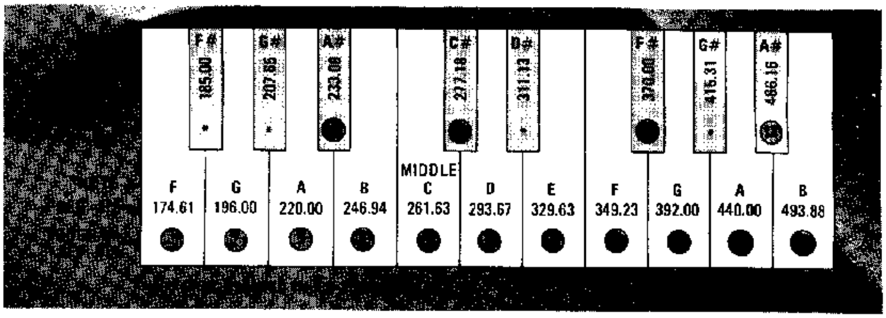


FIG. 1— 1½ OCTAVES on a piano-style keyboard. Circled numbers refer to values contained in the tone-generation program.

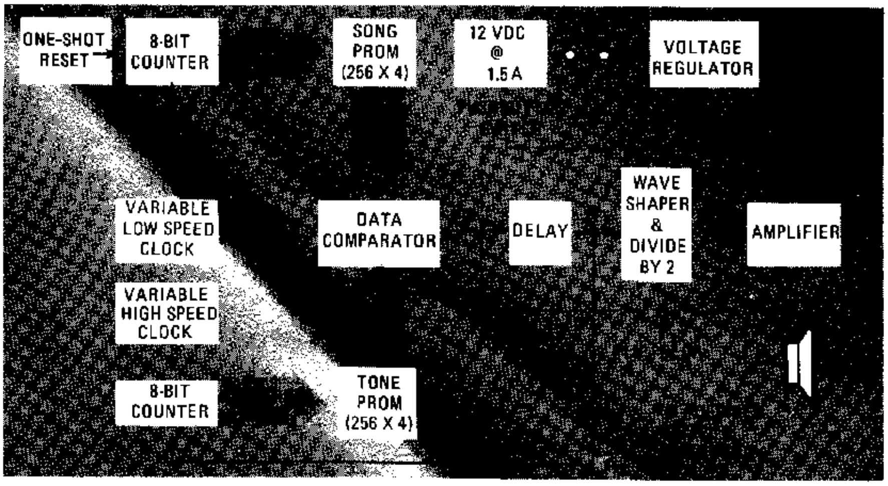


FIG. 2—HEART OF THE MUSICAL HORN is the data comparator, which determines when, and for how long, each tone will sound.

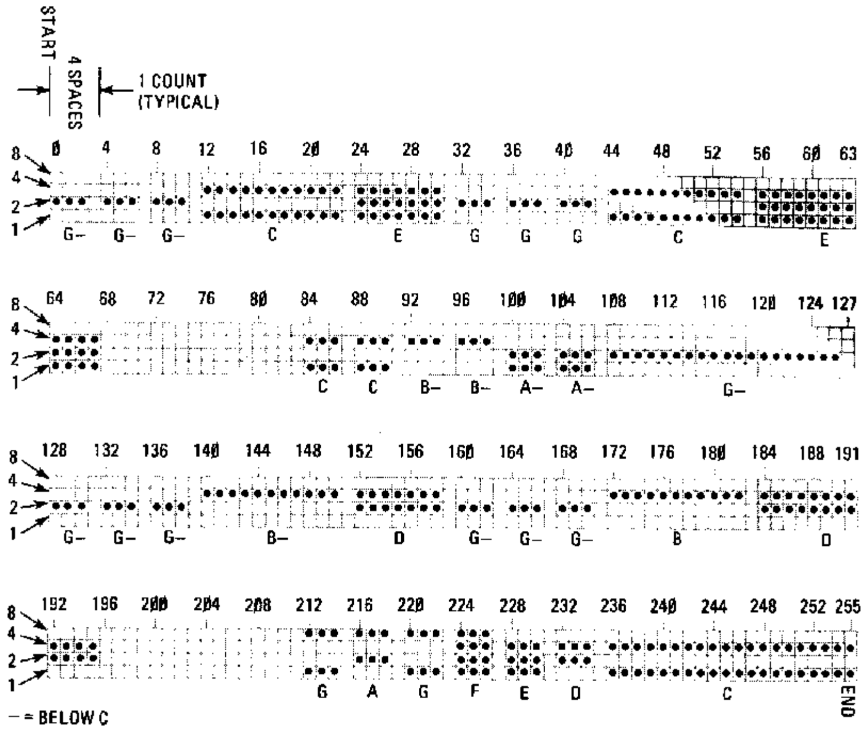


FIG. 3—SONG PROGRAM for "La Cucaracha." Program starts at upper left. Dots represent logic-highs; blanks, logic-lows.

binary output sequentially addresses a "tone" PROM with 256 locations. Certain specific addresses in this PROM contain a 4-bit code that corresponds to one of 15 possible tones, or a space (no tone). At these specific note locations, the 4-bit code for the desired note appears at the PROM's output, and is directed to the *other* set of data-comparator inputs.

When the two data comparator inputs correspond exactly, the comparator outputs a pulse to a flip-flop used as a delay element and wave-shaper. The output of the delay portion of the flip-flop passes the pulse back to the high-speed 8-bit counter and resets it to zero. The second section of the flip-flop changes the pulse to a square wave at one-half of the pulse frequency. The square wave is then amplified and fed to a speaker. The transistor amplifier is operated directly from the 12-volt supply.

What all this amounts to is that the low-speed clock and song PROM determine the specific notes and duration, while the high-speed clock and tone PROM generate each desired note by counting the number of cycles to reach an addressed memory location. This will become clearer as we go through the circuit in detail.

How it works

Figure 4 is the schematic of the horn. A 555 astable multivibrator, IC1, with C1, C2, R1, R2, and R3, generates pulses at pin 3. Their frequency is determined by the setting of R1, the TUNE-SPEED control. It takes 256 pulses for an entire tune, and you can control how fast the complete tune plays by setting R1—from very slow (27 seconds) to very fast (2.3 seconds).

Two 7493's, IC4 and IC5, are cascaded to form an 8-bit counter. The pulses from IC1 clock IC4, a divide-by-16 binary counter. The Q0, Q1, Q2 and Q3 outputs go to IC8 to address the least-significant four bits, A0, A1, A2, and A3, of the 8-bit input. The Q3 output of IC4 (every 16th pulse) also clocks IC5, another divide-by-16 counter, whose Q0, Q1, Q2 and Q3 outputs form the most-significant four bits—A4, A5, A6, A7—to complete the addressing to IC8. Wherever power is applied (switch S1 held closed) IC2 puts out a momentary logic-high pulse at output Q, which resets both IC4 and IC5 to zero. Now each clock pulse from Q of IC1 causes the address to IC8 to advance by one location, from zero to 255. The outputs of IC8, data lines D0, D1, D2 and D3, are inputs to data comparator IC10 at A0, A1, A2 and A3.

The song program

Looking back at Figure 1, notice that most keys have a circled number indicated, as well as a frequency. The circled number is a decimal number from 1 to 15 to represent that particular note. Zero is no note—that is, silence. Not all the keys are numbered, since the 4-bit binary code used in programming these numbers only allows for 0-15 in decimal.

The number 5, for example, represents middle C (261.63Hz). Now look at Fig. 3, the actual programming of IC8 for "La Cucaracha". Start at the lower left corner. The first horizontal row is memory address 0. Each row shows four vertical columns. Each column has a decimal value, going from left to right, of 8, 4, 2, and 1. You may recognize this as a binary sequence, or a 4-bit binary code. A black dot in a column signifies a

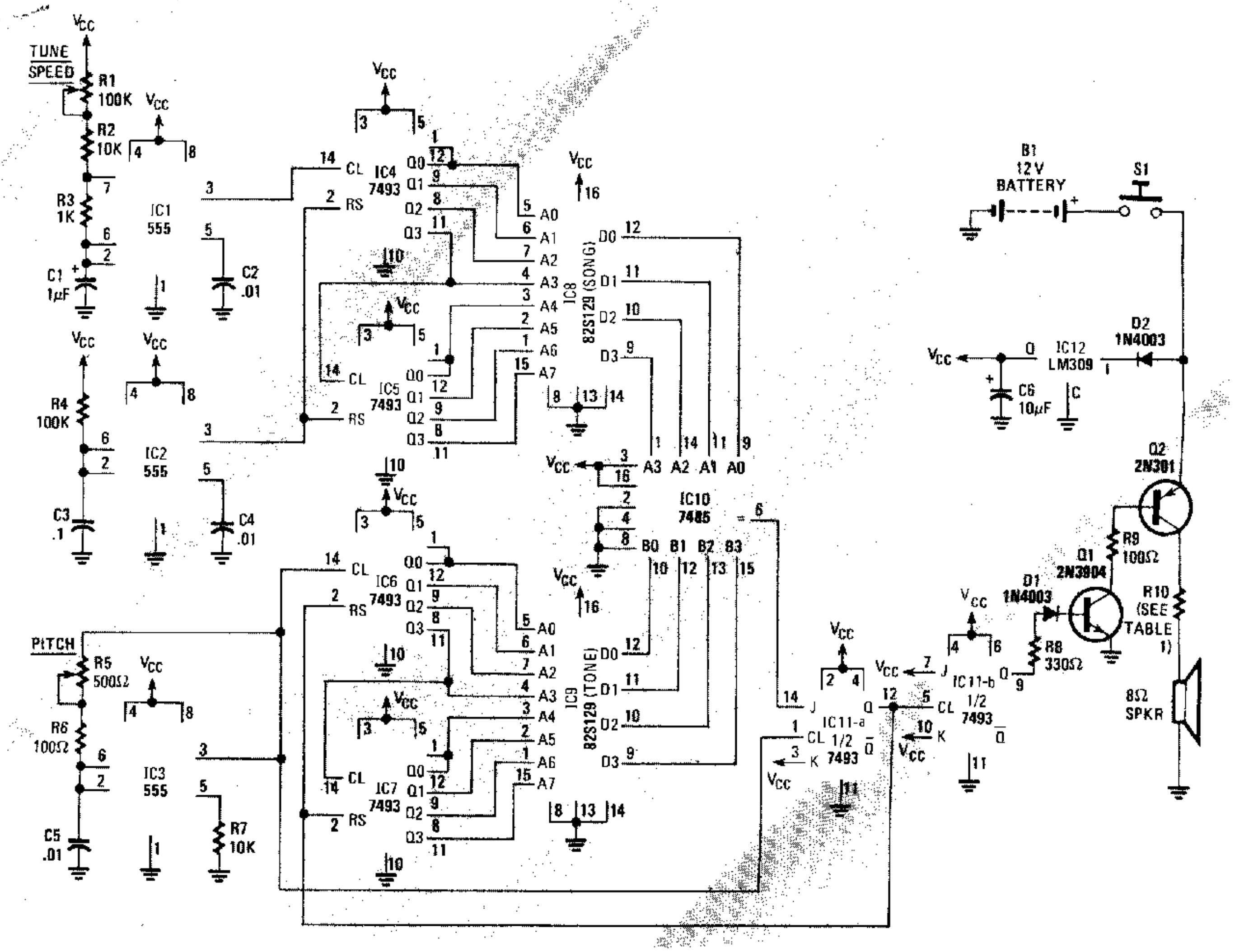


FIG. 4—MUSICAL HORN SCHEMATIC. Transistor Q2, a 2N301, is a special germanium type—do not attempt to use a silicon-type in its place.

PARTS LIST

Resistors ¼-watt, 5% unless otherwise specified
R1—100,000 ohms, potentiometer
R2, R7—10,000 ohms
R3—1000 ohms
R4—100,000 ohms
R5—500 ohms, potentiometer
R6, R9—100 ohms
R8—330 ohms
R10—see Table 1

Capacitors
C1—1 µF, electrolytic
C2, C4, C5—0.01 µF, ceramic disc
C3—0.1 µF, ceramic disc
C6—10 µF, electrolytic

Semiconductors
IC1-IC3—555 timer
IC4-IC7—7493 4-bit binary counter
IC8, IC9—N82S129 or equivalent 256 × 4-bit PROM (see below)
IC10—7485 4-bit magnitude comparator
IC11—7473 dual JK master/slave flip-flop
IC12—LM309K, LM340K or 7805K 5-volt regulator
Q1—2N3904 or similar
Q2—2N301
D1, D2—1N4003, 200 PIV
S1—N.O. momentary pushbutton switch

Miscellaneous: PC board, 8-ohm speaker or horn, IC sockets, hardware, etc.

NOTE: The following are available from PPG Electronics, Dept. RE, 14663 Lanark St., Van Nuys, CA 91402: Complete kit including PC board and all parts except case and IC8 (No. 1082), $39.95; PC board only (No. 782), $11.95; IC9 tone PROM (PPG-0), $6.95; IC8 song PROM ("Cucaracha": PPG-1, "Dixie": PPG-2, "Charge": PPG-3), $6.95 each; 2N301 output transistor, $1.99. Add $2.00 shipping & handling for orders within U.S. CA residents please add 6% tax.

"1" or logic-high output; a blank indicates a "0" or logic-low output. The "1" column corresponds to data line D0 of IC8; the "2" column controls data line D1; "4" controls D2, and "8" determines the output at D3. Putting all that together, the black dots for each row (memory address) of IC8 determine the logic states of the four data-output lines. When IC4 and IC5 input an address to IC8, what they do in effect is to look at the contents of that address and set the output data lines to the corresponding logic levels.

Confused? Well, another sketch (Fig. 5) and some examples will help. The musical notation shown in Fig. 5 is non-conventional in some respects, but more easily understood by non-musical readers. A "solid" note with a stem is 1 beat, which occupies four memory addresses in the song IC (IC8). An "empty" note with a stem is 2 beats, and needs 8 memory addresses. The legend shows the other symbols and the number or beats associated with them. Each note is shown conventionally on the staff; C is shown one line below the staff, for example. The numbers above the staff represent beats—a total of 64 for the entire tune. (64 beats times 4 addresses per beat equals the total of 256 addresses in IC8).

Looking at Fig. 3 again, we see that address 0 (binary 00000000 from IC4 and IC5) contains a black dot in only the

"2" column. This means that the 4-bit binary code for 2 (0010) will appear at the output data lines of IC8. The number "2" corresponds here to the note "G" (below "C") in Fig. 1 and is also the first note shown in Fig. 5, with a duration of 1 beat. Remember, 1 beat takes 4 memory locations in the song chip. However, the end of each note is cut off one-quarter beat short to signify the end of that note, so only address locations 0, 1, and 2 are programmed with a "2". Location 3 is blank—silence. Locations 4, 5, and 6 and then 8, 9, and 10 also hold a "2" in memory. This means that, so far, three distinct "G" notes have been commanded, each with a single beat duration (beats 1, 2 and 3), just as shown in Fig. 5.

The next note we want is a "C" for beats 4, 5, and 6. That begins at IC8 memory address 12 (binary input from IC4 of 1100 and from IC5 of 0000). Here, black dots are in columns 4 and 1, for a binary output from IC8 of 0101, decimal "5." This corresponds to "C" in Fig. 1. The note duration continues through IC8 address 22, followed by a zero at address 23 to cut off the note after 3 beats. Addresses 24 through 30 play the note "E" (decimal "7" in Fig. 1) for 2 beats as shown by the Fig. 5 score. "Rests," such as beats 18 thru 21, are simply blank memory locations for that duration.

The tune program continues through address 255 and then starts again at 0.

Tone generation

So far, IC8 has defined the note and duration commands, but how do the notes actually get generated? Refer back to the schematic (Fig. 3).

Another 555, IC3, with capacitor C5 and resistors R5, R6, and R7, generates pulses at pin 3 at a frequency determined by the setting of PITCH potentiometer R5. Those pulses are from 500 to 1000 times faster than the tune-speed pulses from IC1. The IC3 pulses clock binary counter IC6, which cause IC6 and IC7—another pair of 7493's—to upcount in the same manner as described earlier for IC4 and IC5. The 4-bit binary outputs of IC6 (least-significant bits) and IC7 (most-significant bits) form an 8-bit address word for IC9, another 256 × 4 PROM. That PROM is specially programmed to generate tones. Figure 6 shows the memory locations for each note in IC9. Here's how a tone is generated:

FIG. 5—SIMPLIFIED SCORE for "La Cucaracha." Horizontal rectangles represent "rests"—periods when no music is played.

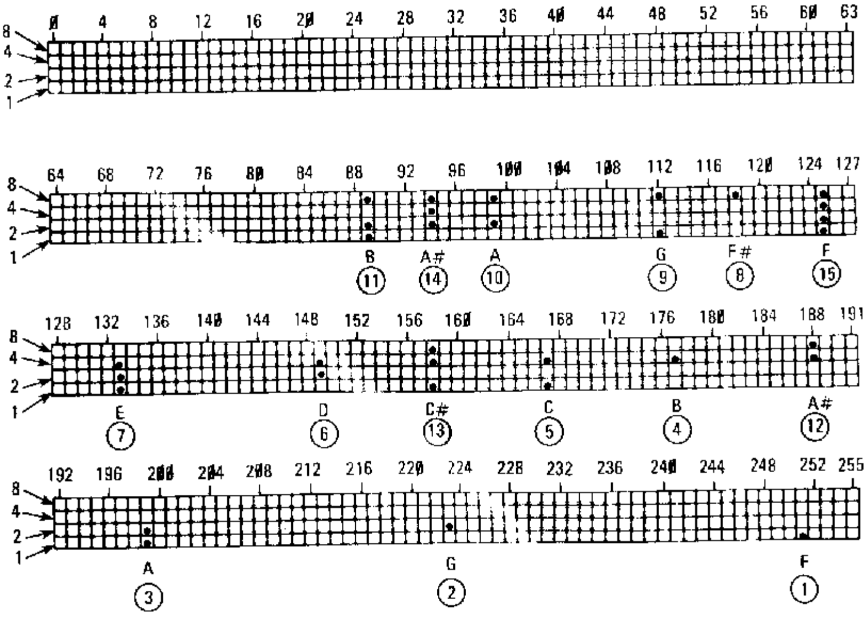
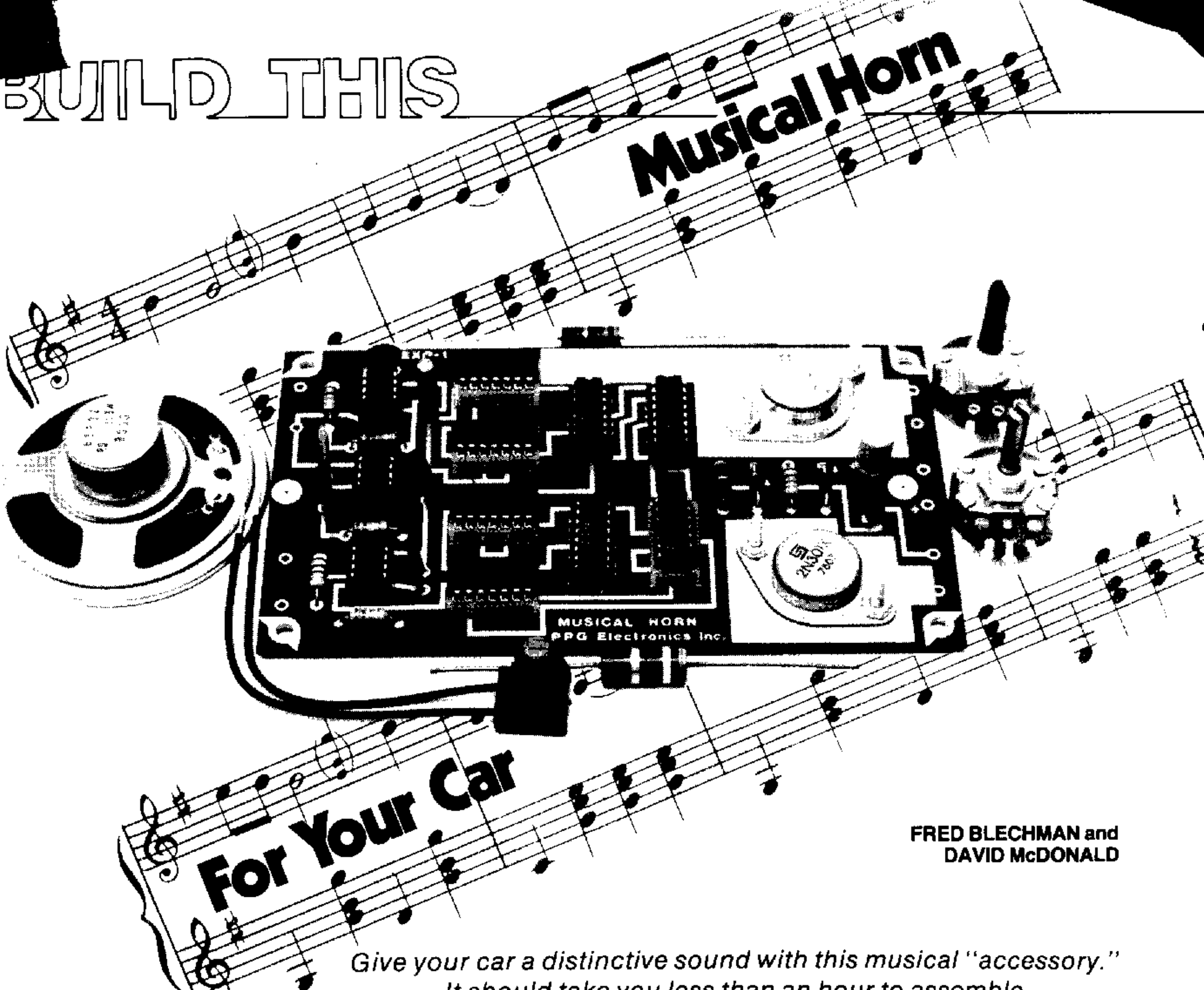


FIG. 6—TONE GENERATOR program. Start reading at upper left. The lower the number assigned to a note, the lower its frequency (see text).

As IC6 and IC7 count upwards at the frequency generated by IC3, the output of IC9 at each count is that contained by the memory location addressed at that instant. That output is fed from data lines D0, D1, D2, and D3 to the B0, B1, B2, and B3 inputs of IC10, a 7485 data comparator. Remember that the binary output of IC8 at that point is being fed to the "A" inputs of IC10, which is looking for an exact match at its "A" and "B" inputs. Only when the "A" and "B" inputs of IC10 are identical does IC10 generate a logic-high output at pin 6. As IC6 and IC7 address the memory locations of IC9, most locations are "blank" (all zeros). Finally, at decimal address 89 the binary number 1011 appears (decimal 11 or musical note "B" in Fig. 1). This is, at that moment, the "B" input to IC10. If the "A" input also has this same input (1011) then pin 6 of IC10 goes high, and IC6 and IC7 are reset to zero by a pulse from pin 12 of IC11-a. If, however, the "A" input is *not* 1011, but instead is the command for a *different* note, then IC6 and IC7 keep counting upward. Decimal address 94 contains the binary code 1110 (decimal 14), which would be the next lower frequency musical note, "A#," in Fig. 1.

We'll finish discussing how the Musical Horn generates tones when we conclude this article next month. We'll also give you some pointers that will help make building and troubleshooting the circuit much easier. After all that's done, we'll show you how to mount the Musical Horn in your car. **R-E**



BUILD THIS

Musical Horn For Your Car

FRED BLECHMAN and
DAVID McDONALD

Give your car a distinctive sound with this musical "accessory." It should take you less than an hour to assemble.

Part 2

WE WERE EXAMINING how tones were generated by the musical horn when we stopped last month. Now we'll finish up.

Whenever a match is found between the output from IC8 and the output from IC9, then IC6 and IC7 are reset at the frequency of the note called for by IC8, until the input to IC8 changes. The greater the number of counts IC6 and IC7 produce before reaching the IC8-IC9 matching-address, the longer the time period for each reset cycle, and therefore the *lower* the frequency of the note that is produced.

Let's use some actual numbers to illustrate this. Suppose IC3 is adjusted by R5 to pulse at 87560 Hz. To produce a 220-Hz musical note, "A," binary code 0011 (decimal 3), at address 199 of IC9, is used. Each second IC3 counts up to that memory location 440 times (87560/199=440). Each time location 199 is reached, a 0011 output appears at the "B" input of IC10. With the "A" input to IC10 also 0011, a pulse appears at IC10 output-pin 6—in this case, at the rate of 440 times per second. This is converted to a square wave with a frequency of 440/2, or 220 Hz, by flip-flop IC11-b, and this is the frequency fed to the amplifier.

Using the same IC3 pulse rate, if the musical note "E" (decimal 7) were specified by IC8, then address 133 of IC9 would contain the matching binary code (see Fig. 6) and would cause IC10 to output pulses at the rate of 658.35 per second (87560/133=658.35). That would be divided in half by IC11-b to 329.18, very close to the ideal 329.63-Hz frequency of "E-above-middle-C." Figure 6 shows all the musical notes programmed in IC9 by location, along with the decimal code notation used in Fig. 1. (Figures 1 and 6 appeared in last month's issue.)

The 7473 dual J-K flip-flop, IC11, requires a little explanation. Input K of IC11-a is connected to V_{CC}. Since J is low, Q is low. Whenever input J goes high (because of an output pulse from IC10), the next time the clock pulse from pin 3 of IC3 goes low, the Q output (pin 12) of IC11-a goes high and resets IC6 and IC7. That stretches the length of the reset pulse to equal the duration of the clock period of IC3, making it wide enough to be recognized by IC11-b. The resetting routine may occur hundreds of times per second, depending on the settings of R1 and R5, and on the note and duration called for by the song PROM.

With both J *and* K inputs tied to a positive voltage, IC11-b is used as a toggle flip-flop. Every time the Q output of IC11-a goes low, it clocks IC11-b and causes the IC11-b Q output, at pin 9, to change state. The result is a square wave output from IC11-b equal in frequency to one-half the IC10 pulse frequency. The squaring of the IC10 pulses results in a sound more closely resembling that produced by a sine wave.

Positive halves of the square wave from pin 9 of IC11-b pass through dropping resistor R8 and isolation diode D1 to bias NPN transistor Q1 into conduction. That path now provides, through R9, the forward base-bias for power transistor Q2 to conduct heavily,

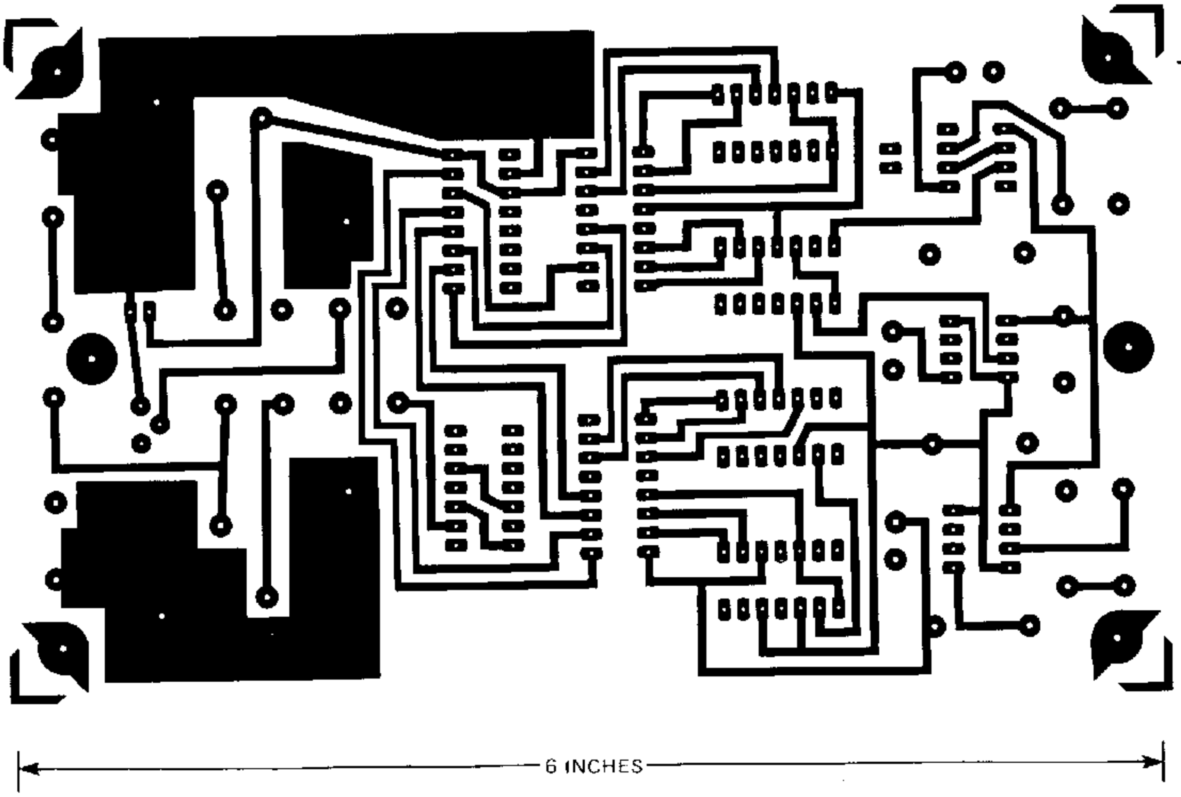


FIG. 7—PATTERN FOR FOIL SIDE of double-sided PC board. See Parts List for availability of ready-to-go boards if you don't want to make your own.

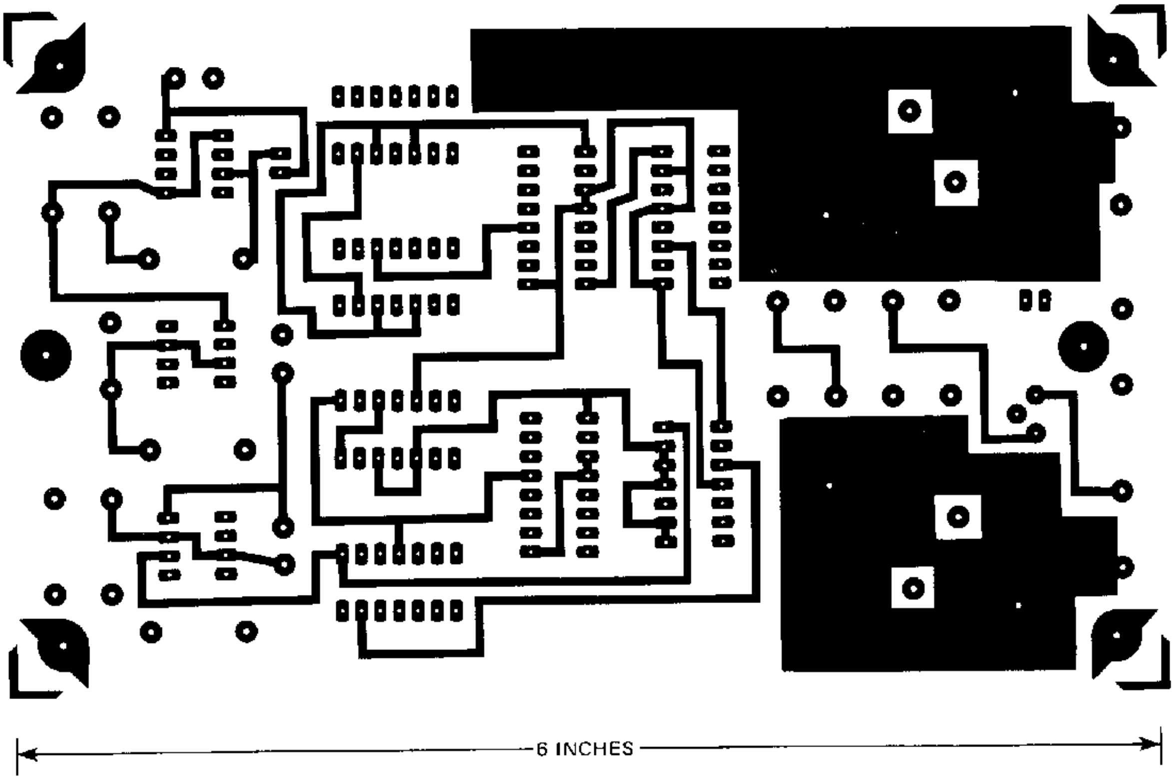


FIG. 8—COMPONENT-SIDE foil pattern. Both sides of the board must be in perfect register. Holes should be plated-through.

passing current through the speaker coil. Resistor R10 is a 2-watt series current-limiting resistor which must be used with speakers rated at less than 10 watts, as shown in Table 1.

A five-volt regulator, IC12, is protected from reverse-voltages by diode D2. Its output is filtered by C6. Switch S1 is used to operate the horn.

A song can be played in different keys as each note is not "locked-into" a specific frequency. In a musical scale each note bears a fixed mathematical relationship to every other note. You can vary the frequency of the notes as long as all the notes maintain the same relationship. PROM IC9 establishes that relationship, so you can vary song-speed with R1 and change the pitch (key) by adjusting R5.

One final note: When IC8 is programmed for "silence" (binary 0000) it actually causes "matching" at an ultrasonic frequency with the first address in

TABLE 1

SPEAKER RATING	RESISTOR (R10)
.25 watt	39 ohms
.5 watt	27 ohms
1 watt	16 ohms
5 watts	3 ohms
10 watts	none

Note—If a speaker rated at less than 10 watts is used, a current-limiting 2-watt resistor must be used in series with the speaker.

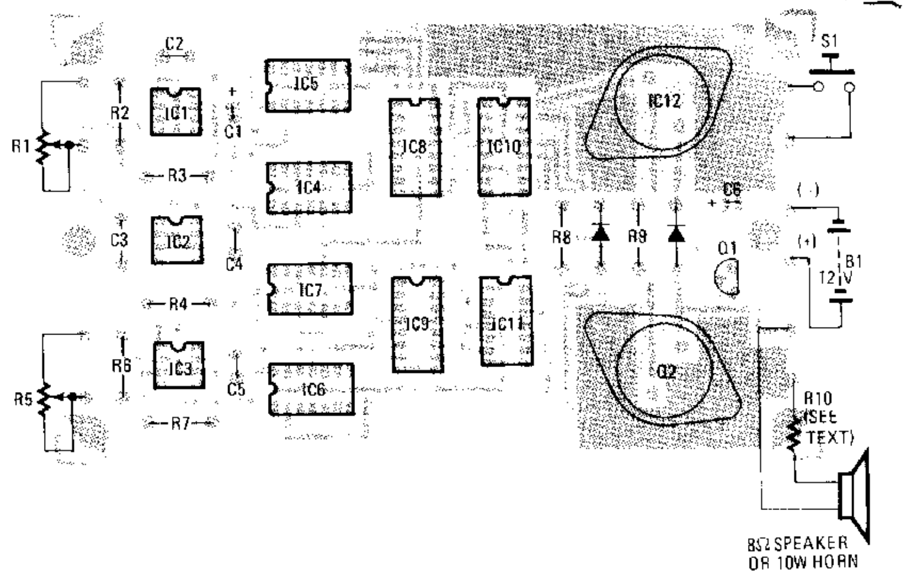


FIG. 9—BE CERTAIN that diode and capacitor polarities are correct. Packages for IC12 and Q2 are nearly identical—do not confuse one for the other.

IC9, which also is binary 0000. This causes slightly more current than might beexpected to be drawn from the battery, due to the high-speed saturation effects of Q1 and Q2 (fast turn-on and slow turn-off).

Construction

You can build this project on construction board, or use the double-sided printed circuit board layouts shown in Figs. 7 and 8. However, if you make your own boards you must be very careful to have good registration between the top and bottom surfaces. Furthermore, unless you are able to plate through the holes after drilling, you will have to solder each component on *both* sides of the board, since many circuit paths depend on continuity through the board!

Frankly, the double-sided, plated-through PC board offered for this project (see Parts List in last month's issue) is the most practical way to go. A parts kit, including sockets for all IC's and the tone PROM, but not including case, is also available.

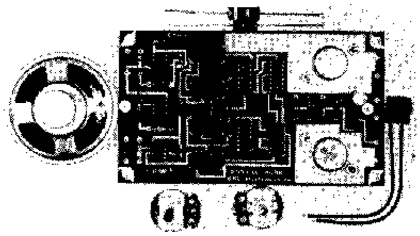


FIG. 10—COMPONENTS SURROUNDING BOARD can be mounted along with it in plastic case under the dashboard. The speaker or horn, of course, is located behind car's front grille.

Assembly should take less than an hour, and requires no special techniques. Use a small-tip 25-45 watt soldering iron and good rosin-core solder. All parts are mounted on the component side of the board. Insert and solder all the resistors first; be very careful to get the right values in the proper locations, as shown in the parts-placement diagram (Figure 9). Install all the IC sockets next, being careful not to install 14-pin sockets in 16-pin locations! Bend down the corner pins of each socket on the underside of the board to hold the socket firmly in place before soldering. Now install the two diodes (watch the polarity—the banded ends should point toward IC12). Next install the three small flat disc capacitors and then the larger one. Be careful when you install the two electrolytic capacitors; they are different values andalsomust be oriented correctly.

Transistor Q2 and voltage regulator IC12 look alike—don't mix them up! IC12 is clearly marked "LM309 or LM340", but Q2 may have numbers *other* than "2N301" (such as SP-2540.) Put each onein the proper location and secure it to the printed-circuit board with 6-32 hardware. Now insert and solder the small transistor, Q1.

You can either program the two PROM's, IC8 and IC9 (N82S129's or 74S287's) yourself (see the "Inexpensive PROM Programmer" in the February 1981 issue of **Radio-Electronics**), using the information provided last month in Figs. 3 and 6, or obtain them pre-programmed from the source indicated in the Parts List.

Insert the IC's into their sockets, being careful that the notched or indented (pin-1) ends are oriented as shown in Fig. 9.

The finished board should look like the one in Fig. 10.

Checkout

You should test the unit before packaging it up. Solder short leads (bare wires clipped from resistors after soldering them to the board, for example) to the PC-board pads that will connect to the two potentiometers, the switch, the power supply, and the speaker. Use alligator-clip leads to make the test connections from them to the outboard components. When connecting the potentiometers, the center and left terminals (looking at the front of the potentiometers) are the active ones. The right terminal can be left unconnected or wired to the center terminal, as you wish—it makes no difference electrically. The

continued on page 100

PARTS LIST

Resistors ¼-watt, 5% unless otherwise specified
R1—100,000 ohms, potentiometer
R2, R7—10,000 ohms
R3—1000 ohms
R4—100,000 ohms
R5—500 ohms, potentiometer
R6, R9—100 ohms
R8—330 ohms
R10—see Table 1
Capacitors
C1—1 μF, electrolytic
C2, C4, C5—0.01 μF, ceramic disc
C3—0.1 μF, ceramic disc
C6—10 μF, electrolytic
Semiconductors
IC1-IC3—555 timer
IC4-IC7—7493 4-bit binary counter
IC8, IC9—N82S129 or equivalent 256 × 4-bit PROM (see below)
IC10—7485 4-bit magnitude comparator
IC11—7473 dual JK master/slave flip-flop
IC12—LM309K, LM340K or 7805K 5-volt regulator
Q1—2N3904 or similar
Q2—2N301
D1, D2—1N4003, 200 PIV
S1—N.O. momentary pushbutton switch
Miscellaneous: PC board, 8-ohm speaker or horn, IC sockets, hardware, etc.

NOTE: The following are available from PPG Electronics, Dept. RE, 14663 Lanark St., Van Nuys, CA 91402: Complete kit including PC board and all parts except case and IC8 (No. 1082), $39.95; PC board only (No. 782), $11.95; IC9 tone PROM (PPG-0), $6.95; IC8 song PROM ("Cucaracha": PPG-1, "Dixie": PPG-2, "Charge": PPG-3), $6.95 eacn; 2N301 output transistor, $1.99. Add $2.00 shipping & handling for orders within U.S. CA residents please add 6% tax.

MUSICAL HORN

continued from page 58

switch should be a normally-open type. If you use a speaker rated at less than 10 watts, see Table 1 for the series resistor to use. If you're not sure of the speaker rating, use a 39-ohm, 2-watt resistor to be safe. Bear in mind that driving a 10-watt horn speaker with no resistor provides the loudest, most directional, sound.

Be particularly careful about the power connections. Use fairly heavy leads, and make sure that the positive side of the power source is connected to the positive-input lead. The power source should be 12 volts, capable of providing over 1 ampere of current. That means a 12-volt car battery or heavy-duty power supply!

Troubleshooting

If you don't get a melody, disconnect the board from the power source and remove the song PROM, IC9. Now reapply power, press S1, and you should hear a steady tone. If not, check your connections and the polarities of the diodes and capacitors, make sure the correct components are in the correct locations, and make sure that Q1 is inserted correctly. Next verify the orientation of all IC's—and check for bent-under pins. Defective IC's are rare, but they may be checked most easily by substitution, if no other problems are found.

Packaging

This unit is intended to be used in a vehicle, drawing power from the vehicle battery. No power is drawn except when switch S1 is held down. The unit should be installed in a plastic case under your dashboard (not in the engine compartment) with the potentiometers, speaker jack and switch on the cover, and a power supply jack on the side, for example. Use a 3-amp fuse in the power leads, and use heavy wire for the leads and speaker connections. Mount the speaker somewhere behind the vehicle's grille. **R-E**