PORTABLE ELECTRONIC ORGAN

If you don't play a keyboard instrument but would like to learn, you might consider starting out on one of the two simple easy-to-build organs described here. One plays melody; the other also plays chords.

I. QUEEN

MUSIC IS A POPULAR AND SATISFYING HOBBY, judging by the continuing sales of hi-fi equipment, FM receivers, tapes and discs. Listening to music is a pleasure, but playing your own instrument can be doubly satisfying and challenging. After experimenting with several types of audio oscillators and construction plans, I completed a simple organ that measures $14 \times 4\frac{1}{2} \times 1\frac{1}{2}$ inches and plays $2\frac{1}{2}$ octaves. It uses a single oscillator and can play any melody. This instrument was so successful that I then constructed a more sophisticated model that can play *chords* as well as the melody. This one covers 3 octaves. We'll take a look at how to build both models.

Playing an organ

It is amazing how quickly one can learn to play an organ, especially with the help of books written for piano beginners. First, we will give some simple music theory for those readers who are not familiar with it.

The human ear is a sensitive detector of frequency ratios. For example, it easily recognizes a ratio of 2:1. The higher frequency is said to be one *octave* above the other. Since piano and organ keyboards cover an extensive range of frequencies, let's use an octave as a convenient interval of sound. Each octave is divided into 12 equal geometric steps, each step representing a change of about 6%.

The keyboard is arranged so that a musician can distinguish and identify a particular key out of the 12 in each octave. The keys are arranged in 2 rows: one with seven white keys, the other with five black keys forming a pair and a trio (See Fig. 1). A letter of the alphabet, from A to G, is assigned to each of the seven white keys. The word "sharp" (written as ♯) may be applied to a black key to indicate one step *higher*. For example, F♯ is one step above F. Sometimes it is more convenient to use the word "flat" (shown as ♭) to indicate a black key that is one step *lower*. For example, B♭ is one step below B. Obviously, A♯ and B♭ refer to the same black key.

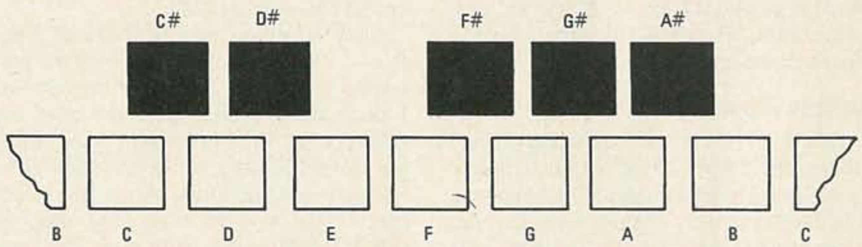


FIG. 1—HOW KEYS ARE ARRANGED on the home-built organ. You can salvage individual keys from an old electronic calculator or purchase them from a surplus parts dealer.

An inexpensive keyboard can be constructed with individual calculator keys, approximately $\frac{3}{4}$-inch square, that you can take from an old calculator, or purchase from a surplus parts dealer.

Poly Paks for instance has carried switches that are easy to operate, and have low resistance. They come in sets of 4 switches, one of which is a dummy switch without leads. You can remove the inoperative switch and substitute a good one from another set. A set of 4 switches can also be sawed apart to make a group of 2 or 3, which are needed for the black keys. Key caps are sold that mate with the key switches.

Radio Shack has sold individual calculator keys, and some stores may still stock them. They are fairly good and can be cemented down on any flat surface.

(Neither of the switches we used are currently available from Poly-Paks or Radio Shack but you are sure to find suitable substitutes if you keep an eye on ads and catalogs from surplus parts dealers. Any SPST pushbutton switch can be used provided it is large enough to be comfortably used in a keyboard. Simply modify the switch mountings and organ housing to match the switches you use.—*Editor*)

Building the organ

The top and bottom of the organ are made of three-ply wood, held in place by aluminum supports at the front and rear, as shown in Fig. 2. Two L-shaped lengths of aluminum that are held together with machine screws form each U-shaped support. The aluminum comes in 6-foot lengths and measures 1 inch on each side. It is readily available in hardware stores.

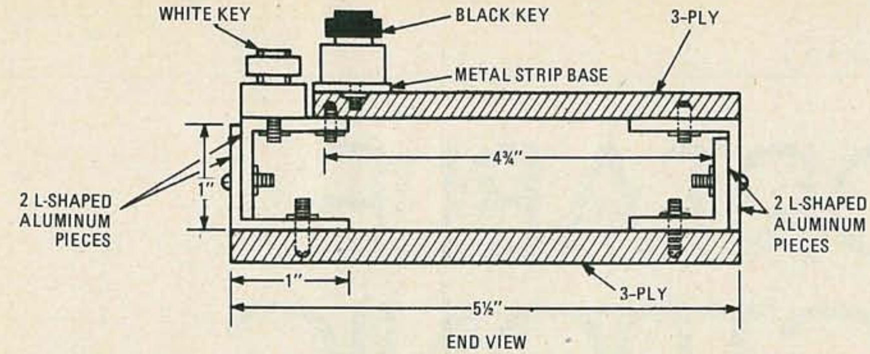


FIG. 2—PUTTING THE ORGAN TOGETHER. Drawing shows mechanical cross-section. Keys are mounted so the black ones are higher and farther back than the white ones; as on a piano keyboard.

TABLE 1

C♯	139	Hz	G	196	Hz
D	147	Hz	G♯	208	Hz
D♯	156	Hz	A	220	Hz
E	165	Hz	A♯	233	Hz
F	175	Hz	B	247	Hz
F♯	185	Hz	C	262	Hz

See Fig. 6 for higher tones.
Frequencies in Hz.

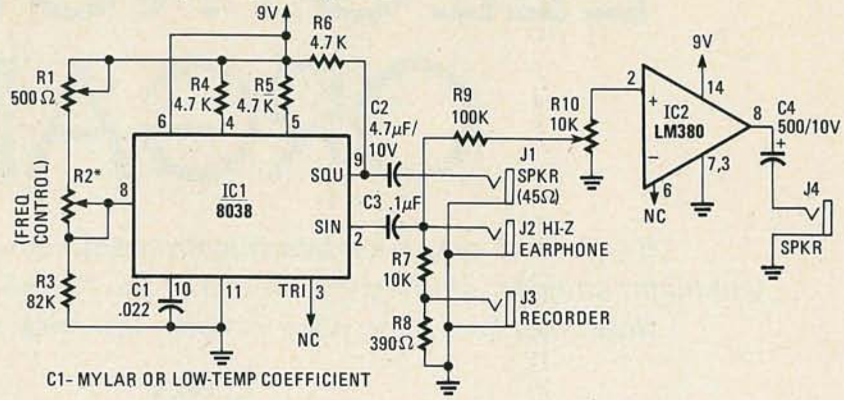


FIG. 3—SIMPLE MONOPHONIC ORGAN plays melodies—one note at a time. Circuit is based on IC1, a voltage-controlled oscillator tuned by the value of resistor R2.

For a 3-octave range, the length of the organ should be about 18 inches.

Note that the top of the organ is narrower than the bottom. This allows you to use a convenient metal base to mount the white keys right in front. The black keys should be slightly behind and somewhat higher than the white ones. Some types of keys have a flat bottom and are made to be cemented onto any flat surface. The Poly Paks key sets came with No. 2-56 screws extending from the bottom. With No. 2-56 hex nuts, I mounted the sets on a metal strip, since the screws are not long enough to pass through the plywood. Then, the metal strip was mounted on the plywood, with the aid of machine screws. Use a strip about three inches long to hold 3 black keys, and another strip about 2¼ inches long for 2 black keys.

Below each key, drill holes for the leads to pass through to the terminals.

Mount the power and the output jacks, as well as the volume control, on the rear metal panel.

To build either organ model, you must have a frequency meter that can measure to about 100 Hz. It is suggested that you construct the simpler organ first to get the feel of playing music. If you are still enthusiastic about playing, then go for the more difficult organ.

Melody organ

In Fig. 3, IC1 is a VCO (*V*oltage-*C*ontrolled *O*scillator) whose output frequency varies with the voltage applied to pin 8. The frequency is minimum when the pin is connected *directly* to the positive (+) terminal of the power supply. As R2 increases, so does the frequency. With a 9-volt supply, the minimum frequency is about 130 Hz.

Oscillator IC1 generates three output waveforms: a sinewave (pin 2), a squarewave (pin 9) and a triangular wave (pin 3). (The latter waveform is not used.) The squarewave output is sufficient to drive a 45-ohm speaker directly at J1. The sinewave has a pleasing tone, and can drive a high-impedance earphone at J2 or drive an external amplifier. An internal amplifier, IC2, is provided however. The output at J3 is greatly attenuated for a tape-recorder.

Actually, R2 must be varied in steps for organ music, as shown in Fig. 4. Each resistor is selected to tune to the required frequency when the corresponding switch is closed.

To calibrate the organ, let IC1 warm up and connect a frequency meter at J2. Set R_A for the lowest tone to be played when S_A is closed. In the instrument I built, it is the key of F (175 Hz). Now, select R_B to play the next higher tone when S_B is closed, and so on up the scale. Table 1 lists the frequencies at the low end of the musical scale.

Each resistance in the series, R_B, R_C, R_D . . . increases gradually over the preceding resistance. The first four resistors I used are 82 ohms each, the next five resistors are 100 ohms each. Then, there are three 120-ohm resistors, followed by four 150-ohm resistors, etc. At the upper end of the musical scale, the resistors should be about 300 ohms each. Try for a frequency accuracy of about 0.5% or better. If your resistors are in smaller increments—such as 82, 91, 100, 110, etc.—you can achieve higher accuracy. To reach a desired value, you can connect two resistors in series. Use terminal strips to hold resistors, or solder them directly to each other and to the keys. Hook the ends of resistors to hold them more securely.

Oscillator IC1 is very sensitive to changes in voltage. You must use either a regulated power supply or batteries. If required, R_A can be used to retune the organ to some extent. The socket of IC1 can easily be mounted on a socket adapter

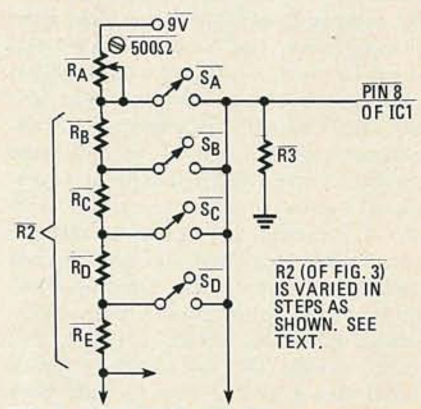


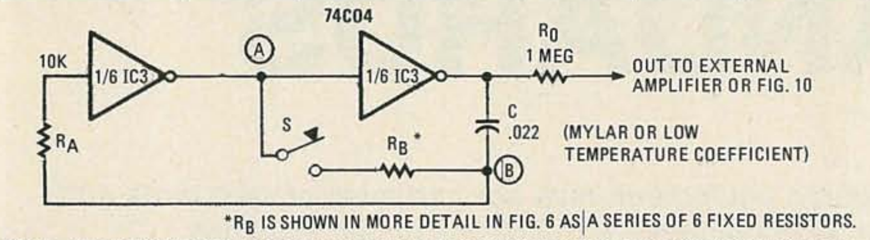
FIG. 4—HOW KEYS ARE WIRED to switch in different resistors to tune the VCO.

PARTS LIST FOR MELODY ORGAN

Resistors are ¼ watt, 5%
R1—500 ohms, potentiometer
R2—calibrating resistors (see text and Fig. 4)
R3—82,000 ohms
R4-R6—4700 ohms
R7—10,000 ohms
R8—390 ohms
R9—100,000 ohms
R10—10,000-ohm potentiometer
C1—.022 µF, Mylar or low-temperature coefficient
C2—4.7 µF, 10 volts, electrolytic
C3—0.1 µF, disc
C4—500 µF, 10 volts, electrolytic
IC1—8038, voltage-controlled oscillator
IC2—LM380 audio amplifier
J1-J4—miniature jacks
Misc.—sockets for audio amplifier, keys (12 per octave), plywood, aluminum supports, hardware (see Fig. 2).

Table 2
(Frequency mHz)

	Oscillator 1	2	3	4	5	6
1st octave	B 247 C 262	C♯ 277 D 294	D♯ 311 E 330	F 349 F♯ 370	G 392 G♯ 415	A 440 A♯ 466
2nd octave	B 494 C 523	C♯ 554 D 588	D♯ 622 E 660	F 698 F♯ 740	G 784 G♯ 830	A 880 A♯ 932
3rd octave	B 988 C 1046	C♯ 1108 D 1176	D♯ 1244 E 1320	F 1397 F♯ 1480	G 1568 G♯ 1661	A 1760 A♯ 1865



*R_B IS SHOWN IN MORE DETAIL IN FIG. 6 AS A SERIES OF 6 FIXED RESISTORS.

FIG. 5—ONE OF SIX OSCILLATORS based on a pair of CMOS inverters. The instantaneous frequency is determined by the value of resistor R_B.

WHAT IS A CHORD?

It is a combination of 3 or more simultaneous tones that harmonize and enhance the playing of a melody. The ear is a sensitive frequency ratio detector. The octave (2:1) was mentioned earlier. If you call *any* note of an organ, 1, and count half-steps upwards, you can show that the pair, 1 and 3, bear the ratio 9:8. Other pairs (and ratios) are: 1 and 4 (6:5), 1 and 5 (5:4), 1 and 6 (4:3), 1 and 8 (3:2). If the 4 notes; 1, 4, 6, 10, are played, it is called a "seventh chord" and combines the following pairs: 1 and 4, 1 and 6, 1 and 3, 1 and 5. The pair, 4 and 6, plays the same frequency ratio as, 1 and 3, since both have the same interval of 2 half-steps. A "major chord" is played, 1, 6, 10. Many other chords, and variations of them, are played in organ and piano music.

PARTS LIST FOR MELODY AND CHORD ORGAN

Resistors are ¼ watt, 5%
R_A—10K (6 resistors, 1 for each oscillator)
RB—Calibrating resistors, selected by trial (see Fig. 6 and text)
R_O—1 MEG (6 resistors, 1 for each oscillator)
C—.022 μF Mylar (6 capacitors, 1 for each oscillator)
Misc.—pair of 74C04 CMOS hex inverters (for building 6 oscillators as in Fig. 5); sockets for inverters; terminal strips for resistors; and plywood, aluminum, hardware, keys, as for organ 1.

(Radio Shack 276-024). I used a small piece of PC board to hold the socket of IC2.

Chord and melody organ

This organ is superior in several ways: It not only plays the melody but also plays chords and contains 3 octaves. It is more stable with respect to frequency and voltage. The IC's consume less power and are less expensive. A disadvantage is that the calibrating resistors vary over a wide range of values, and so are more difficult to select. You may need two or three resistors in series to achieve a desired value. An accurate calibration is desirable since errors are more noticeable when you play chords.

To play chords and melody over three octaves, it at first would appear that we need 36 oscillators, and this thought is unbearable! However, we can simplify. Each oscillator is responsible for two adjacent musical tones (called half-steps), as for example A and A♯. Half-steps are seldom, if ever, played together. This cuts the required number of oscillators by half. Another simplification is to make each oscillator responsible for its own half-steps in *all* octaves. You cannot play the same note in more than one octave. Table 2 shows how six oscillators cover three octaves.

A typical oscillator is shown in Fig. 5. This oscillator is very stable with respect to voltage and temperature. It uses a pair of CMOS inverters operating at 5 volts. One hex inverter such as the 74C 04 can be used to make three oscillators. With R_A and C fixed, the frequency depends only on R_B. A larger R_B means a lower frequency. Of course, the voltage applied to the inverter must remain constant. This oscillator can generate only one frequency at a time. For six different frequencies, you must provide six different values of R_B, each with its own switch (See Fig. 6).

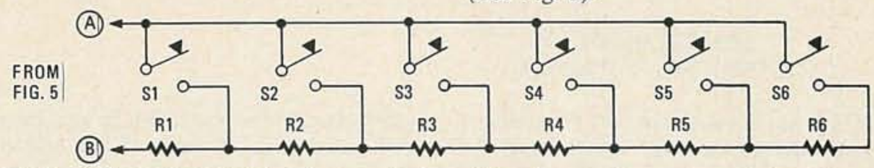


FIG. 6—THE CHORD ORGAN has six monophonic oscillators to cover three octaves. Each oscillator is tuned to six notes selected by the key arrangement shown.

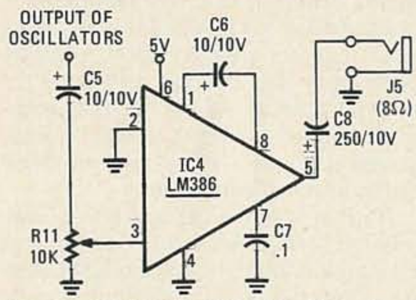


FIG. 7—SCHEMATIC DIAGRAM of the simple power amplifier used in the chord organ.

PARTS LIST FOR AMPLIFIER

R11—10,000 ohms, potentiometer, ¼ watt, 5%
C5, C6—10 μF, 10 volts, electrolytic
C7—0.1 μF, 10 volts, disc
C8—250 μF, 10 volts, electrolytic
J5—miniature jack
IC4—LM386

Calibration

To calibrate the organ, begin with the oscillator 6. Referring to Table 2, select R1 for 1865 Hz when S1 is closed. Then, select a value for R2 to play 1760 Hz when S2 is closed. Next, select R3 to play 932 Hz when S3 is closed, and so on. Similarly, proceed with oscillator 5 and the remainder, observing the frequency meter for correct frequencies. Don't try for an exact frequency in each case, but accuracy should be well within 0.5%. You may need two or even three resistors in series to reach the desired value. Here are the approximate values for the resistors shown in Fig. 6:

Resistor R1 is about 10,000 ohms for oscillator 6; about 12,000 ohms for oscillator 5; 14,000 ohms for oscillator 4, etc. After selecting the value of R1 for any oscillator, the other values in the same series will be approximately as follows:

R2 = .06 R1
R3 = R1
R4 = 2 R2
R5 = 2 R3
R6 = 2 R4

All the output leads (three leads from each oscillator) are tied together, and the signal is amplified. The simple output stage shown in Fig. 7 can be operated from the same power supply as the organ—either a regulated supply or batteries.

The more complex organ obviously requires more patience and time for proper calibration than does the simpler organ. However, it is well worth the extra effort. **R-E**