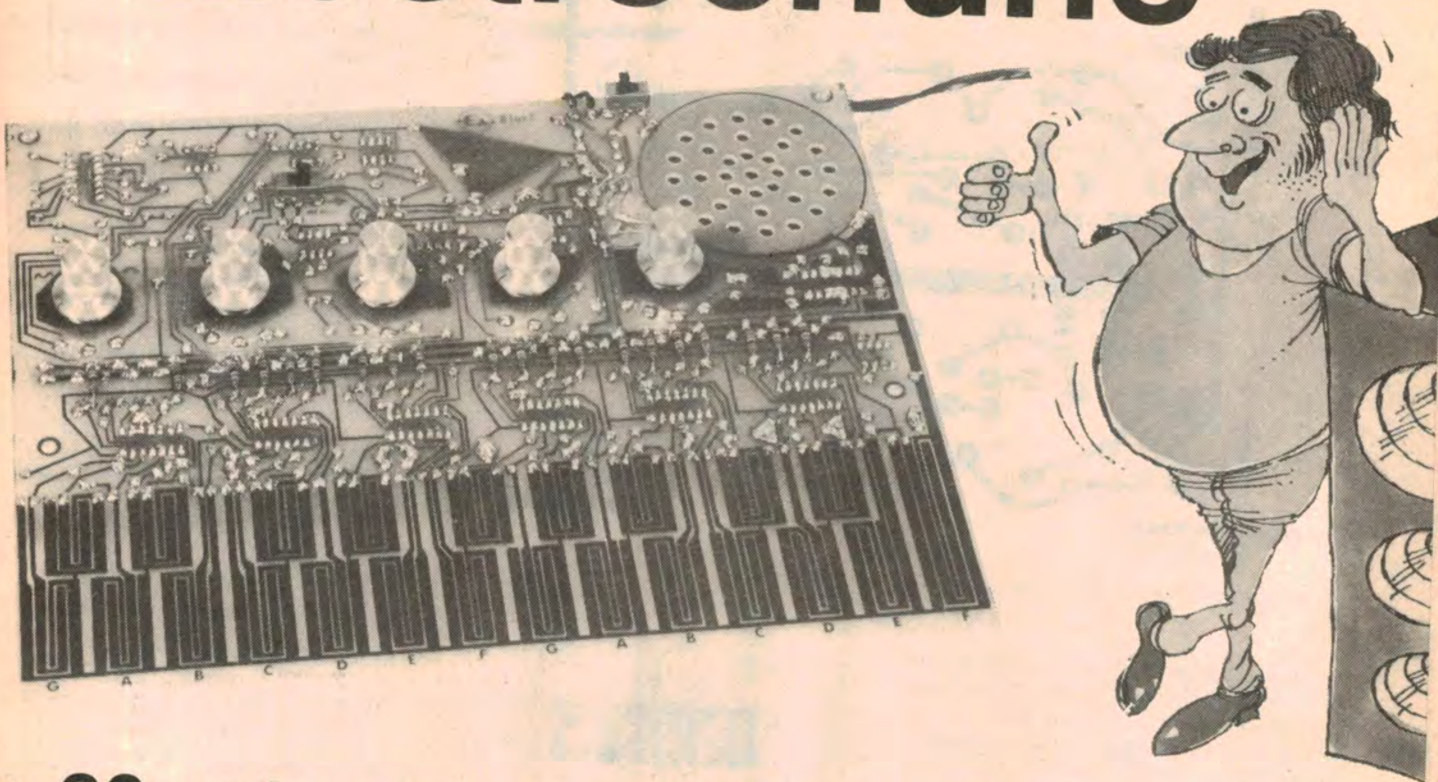
"Electrochune"



a 23-note organ with special effects

Why the name "Electrochune"? Because it's meant to be a fun name for a fun project. We think that readers will really enjoy it, both in the building and in making music. Electrochune is easy to put together, with no expensive hardware, and is capable of a surprising variety of harmonious sounds. Electrochune has a range of almost two octaves, together with sharps and flats, and has six controls for varying its sound output.

by JOHN CLARKE

Electrochune is a complete self-contained keyless organ with all components mounted on a medium-size printed circuit board measuring 249 x 201mm. It can be built in the "bare bones" form shown in our photographs or dressed up with a cabinet, if you wish.

While earlier keyless organs, such as the one published in the January 1969 issue of "Electronics Australia", were played with a stylus, the Electrochune can be played with your finger. Merely touching the "key" areas on the printed circuit board brings each note into action.

Much of the circuitry in the Electrochune is similar to that used in modern synthesizers and so it has some features similar to these popular instruments. For example, like most synthesizers, Electrochune is monophonic. This means that it cannot play chords and is meant to be played one-handed or, really, in this case, one-fingered.

Electrochune is also similar to many synthesizers in that it uses voltage-controlled amplifiers, a sample-and-hold circuit and a voltage-controlled oscillator. As a result it has such features as adjustable attack and decay for envelope control and tremolo. It also has voice mixing and its own inbuilt amplifier and on-board loudspeaker.

Unlike earlier keyless instruments, the Electrochune can be tuned very precisely over its almost two-octave range. This is because each key can be tuned exactly and individually, without affecting any other key. This means that if you want to use the Electrochune seriously, in spite of our remarks at the beginning of this article, you can do so and set up each key so that it is exactly on pitch.

It is also possible to tune the Electrochune to match other instruments. The mind boggles at the possible ramifications of this – you could even have "Electrochune in Concert".

Even though the Electrochune can be tuned very precisely, as noted above, it is not necessary to go to any special bother if you are just building the unit for casual use. Just install the resistor values we have specified and that is the end of the matter.

Electrochune is powered by an AC plugpack. While this will make it initially a little more expensive, it will soon pay for itself by eliminating the cost of batteries.

HOW IT WORKS

While the complete circuit is fairly complicated, the Electrochune is reasonably easy to understand if the circuit is broken down into sections which can be examined one at a time. To this end, look at Fig. 1 which explains the broad principle of the circuit.

Fig. 1 shows the heart of the circuit as a voltage controlled oscillator (VCO). As the name implies, this has a frequency output which is proportional to a voltage applied to its input. The input voltage for each note is fed to the VCO from its individual voltage divider via an individual switch. Since there are 23 notes, there are 23 separate voltage dividers and 23 switches, each of which is actually a switch element in a CMOS quad bilateral switch package.

Following the VCO are the envelope-shaping and tremelo circuits and the audio amplifier and loudspeaker. Now if it were not for the fact that we wish to provide envelope shaping, the simple principle embodied in Fig. 1 would be adequate and the complete circuit diagram would be quite a lot simpler than it is.

By "envelope shaping" we mean giving a precise and defined value to the attack and decay of each note. This means that for a given setting of the controls for attack and decay, each note will sound roughly the same in initial intensity, in duration and in the way it fades into silence. Thus, the envelope of each note will be same regardless of whether the player hits the notes in staccato or slower fashion.

This is quite a refinement compared to previous keyless organs which provided very little facility for expression.

Okay. Now remember that the VCO requires a defined input voltage to produce a given frequency and that it is only while the particular keyswitches are closed that they connect the particular note voltage divider to the VCO. So what happens when the player takes his great greasy finger off the particular key and expects the note to fade away? It doesn't. Because when the input voltage is removed from the VCO its frequency immediately rises to a very high value which is its free-running frequency. Since this would lead to a very unmusical and totally unsatisfactory instrument, we need to provide some means for the circuit to "remember" the VCO input voltage after the key is pressed. This is done with a sample-and-hold circuit and this is incorporated into the scheme of things as shown in Fig. 2.

FREQUENCY OF NOTES USED (Hz)

G	196.0	G	392.0
G'	207.7	G'	415.3
A	220.0	A	440.0
A'	233.1	A'	466.2
B	246.9	B	493.9
C	261.6	C	523.3
C'	277.2	C'	554.4
D	293.7	D	587.3
D'	311.1	D'	622.3
E	329.6	E	659.3
F	349.2	F	698.5
F'	370.0		

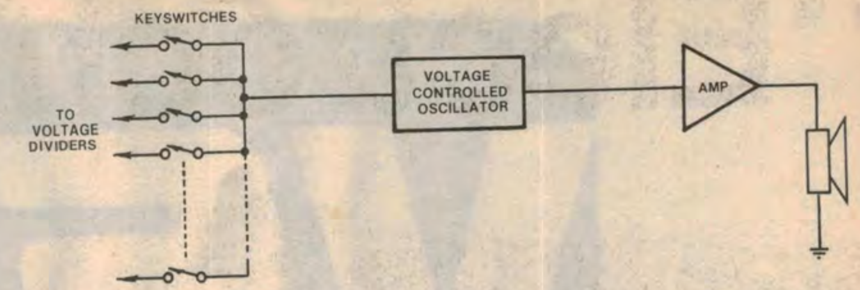


Fig. 1

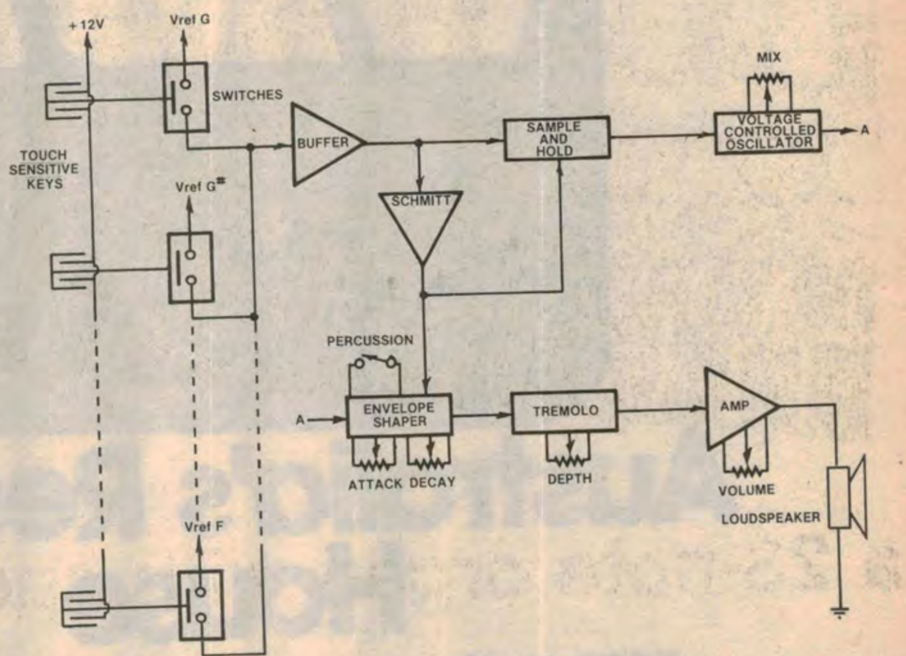


Fig. 2

This block diagram shows an array of switches for the various notes, each with its own voltage divider. When a key is touched, the appropriate CMOS switch is closed, feeding the note voltage through to a FET-input op amp which operates as a buffer stage. The output from this buffer is fed to a conventional op amp functioning as a Schmitt trigger and to a sample and hold circuit. The Schmitt trigger controls the sample-and-hold circuit as well as the envelope-shaping circuitry (for attack and decay) following the VCO. After the envelope shaper a similar circuit provides further signal processing in the form of Tremolo (amplitude modulation). Finally, the signal is amplified and fed to a loudspeaker.

Fig. 3 shows the different functions possible with the envelope shaping and Tremolo circuits.

Now with Fig. 1 and Fig. 2 in mind, we can consider the complete circuit diagram. The heart of the circuit, the VCO, is IC4, which is an Exar 2206 function generator IC. This is connected to provide simultaneous sine and square wave outputs which are mixed across a 5kΩ potentiometer. This provides the necessary range of sine and square waveforms.

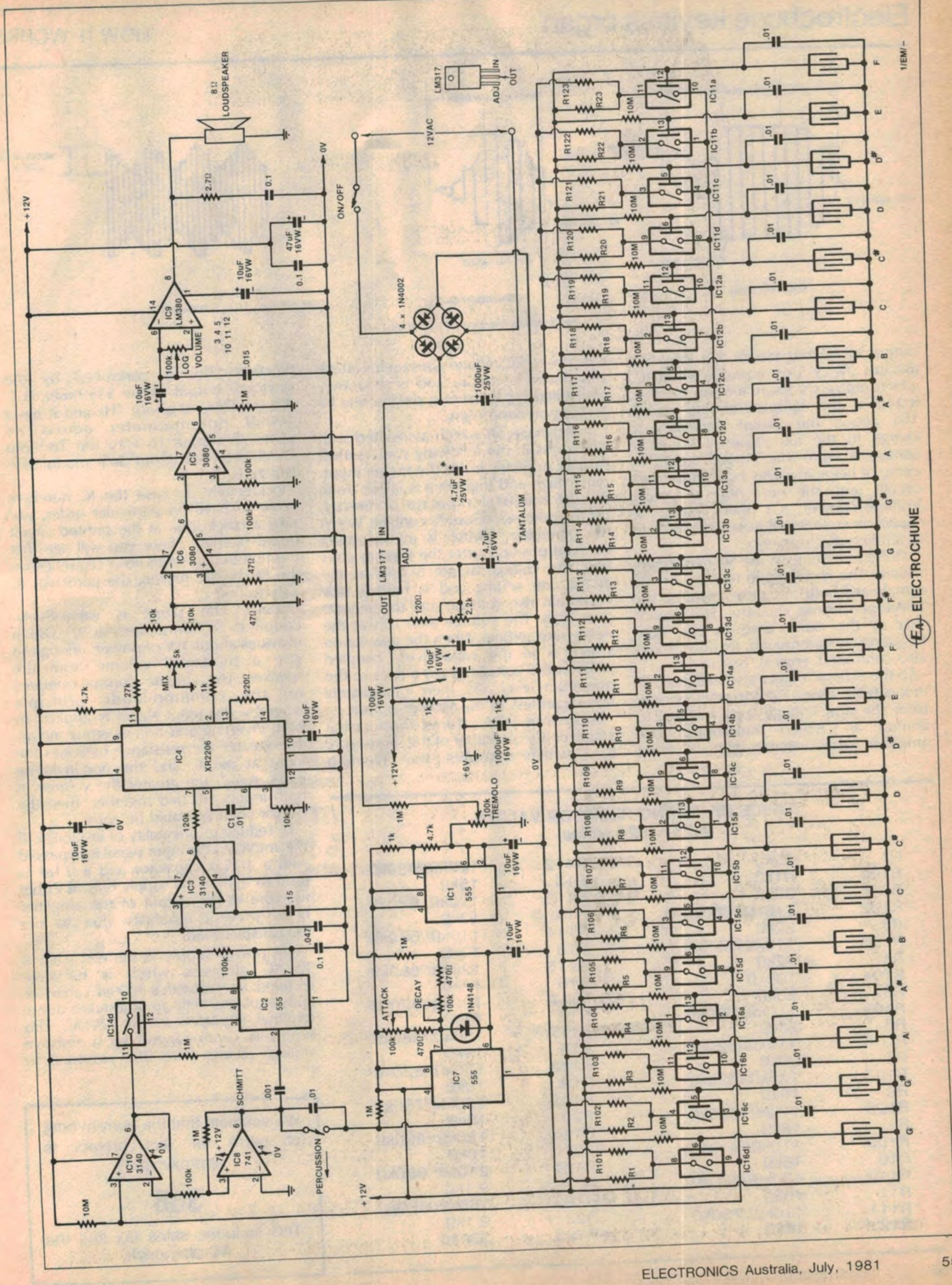
Looking back to the key inputs, ICs 11, 12, 13, 14, 15 and 16 are quad CMOS bilateral switches which provide the input from the note voltage dividers. The CMOS switches are switched by skin resistance of the finger placed across the appropriate key pattern.

The selected note voltage is fed to a FET-input operational amplifier, IC10, operating as a buffer stage. The input of IC10 is normally held high by a 10MΩ resistor, when all CMOS switches are closed. This resistor has a negligible loading effect on the note voltage.

The output of IC10 is fed to IC8, the Schmitt trigger and also to the sample-and-hold circuitry. This consists of a single CMOS switch (IC14d) and IC3, another FET-input operational amplifier connected as a voltage-follower which monitors the voltage across a .047μF capacitor.

SAMPLE-AND-HOLD

As soon as a selected voltage appears at the output of buffer IC10, it drives the


ELECTROCHUNE
1/EM/-
LM317
12VAC
ON/OFF
4 × 1N4002
8Ω LOUDSPEAKER
IC9 LM380
VOLUME
IC5 3080
IC6 3080
MIX
IC4 XR2206
IC3 3140
IC2 555
IC1 555
IC7 555
IC8 741
IC10 3140
SCHMITT
PERCUSSION
ATTACK
DECAY
TREMOLO
TANTALUM
LM317T

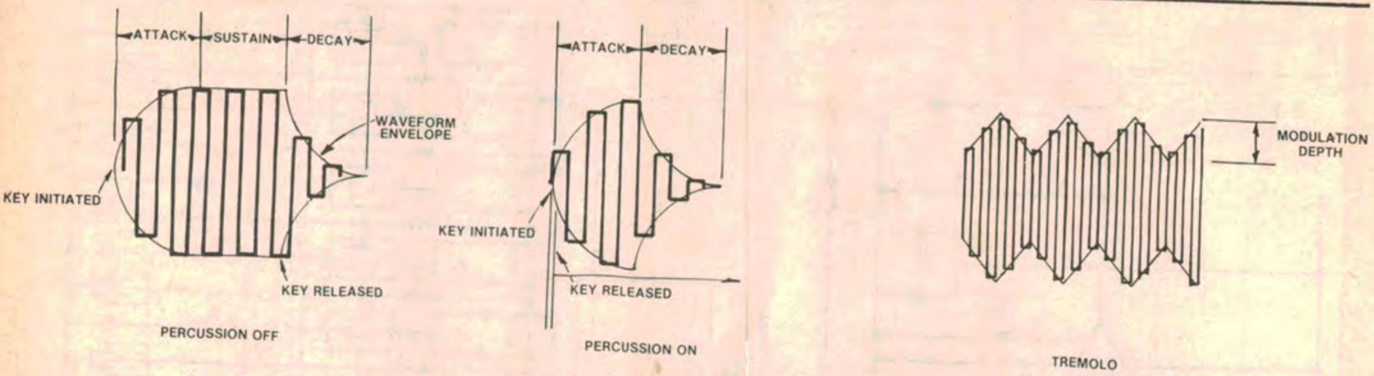


Fig. 3 WAVEFORM ENVELOPE CONTROL

output of Schmitt trigger IC8 low. This initiates the 555 monostable timer IC2 which delivers a short turn-on pulse to IC14d in the sample-and-hold circuit. This allows the .047μF capacitor to charge to the full value of the note voltage, a value which it will "hold", by virtue of being in a very high impedance circuit, until the next note is struck. Voltage-follower IC3 then feeds the capacitor voltage value to the VCO to determine the frequency.

At the same time as the Schmitt trigger initiates the monostable to operate the sample-and-hold, it also initiates the envelope-shaping circuitry. This means that at the same time as the note frequency is determined, its envelope is also controlled. Logical, isn't it?

So the Schmitt trigger also initiates 555 monostable timer IC7 for a set period. Here, the ramp voltage at pin 6 is used to control a CA3080 transconductance amplifier (read: variable gain amplifier) IC6. The ramp voltage goes up for attack and down for decay and is separately controlled for these two parameters by 100kΩ potentiometers.

The percussion switch associated with IC7 works in the following way. A 1MΩ resistor normally holds the trigger input, pin 2, high and triggering is either done through the .01μF capacitor or directly, via the percussion switch contact. When the percussion switch is in the direct coupled position, after the Schmitt goes low, the voltage at pin 6 rises at the attack rate setting and is held at the maximum rise voltage until the Schmitt goes high. The voltage then falls at the decay rate setting. When the percussion switch is in the capacitively coupled position the voltage at pin 6 rises to the maximum level and then immediately falls regardless of the Schmitt output.

Following the transconductance amplifier IC6 is another of the same type, IC5, which provides the Tremolo function. This is controlled by the sawtooth output of the 555 timer, IC1. IC1 oscillates at about 7Hz and it has a 100kΩ potentiometer across its sawtooth output to vary the Tremolo effect between about 30% modulation and zero.

Incidentally, in case the IC numbers seem to have no particular order, just take a quick look at the printed circuit board overlay. There you will see that the numbering refers to a sequence on the PC board, making the particular IC easy to find.

Finally, the signal is capacitively-coupled to amplifier, IC9, which provides about 1W of power, enough to give a substantial volume from the speaker. The volume control operates on the common-mode principle whereby the input signal is applied to both inverting and non-inverting inputs. The greater the resistance between the input at pin 6, and the non-inverting input, pin 2, the greater the volume. If both inputs are tied together, then the output volume would be zero.

To reduce to possibility of instability of the amplifier, the input signal is bypassed with a .015μF capacitor and a 0.1μF is used to bypass the supply rails. A Zobel network at the output of the amplifier helps prevent instability due to the loudspeaker load.

The power supply is derived from a 12VAC plugpack which is full-wave rectified, filtered with a 1000μF capacitor and regulated with an adjustable three-terminal regulator set to 12VDC. This supply is centre-tapped by a resistive voltage divider (two 1kΩ resistors) to

TABLE OF TUNING RESISTOR VALUES
(all 5% E24 series)

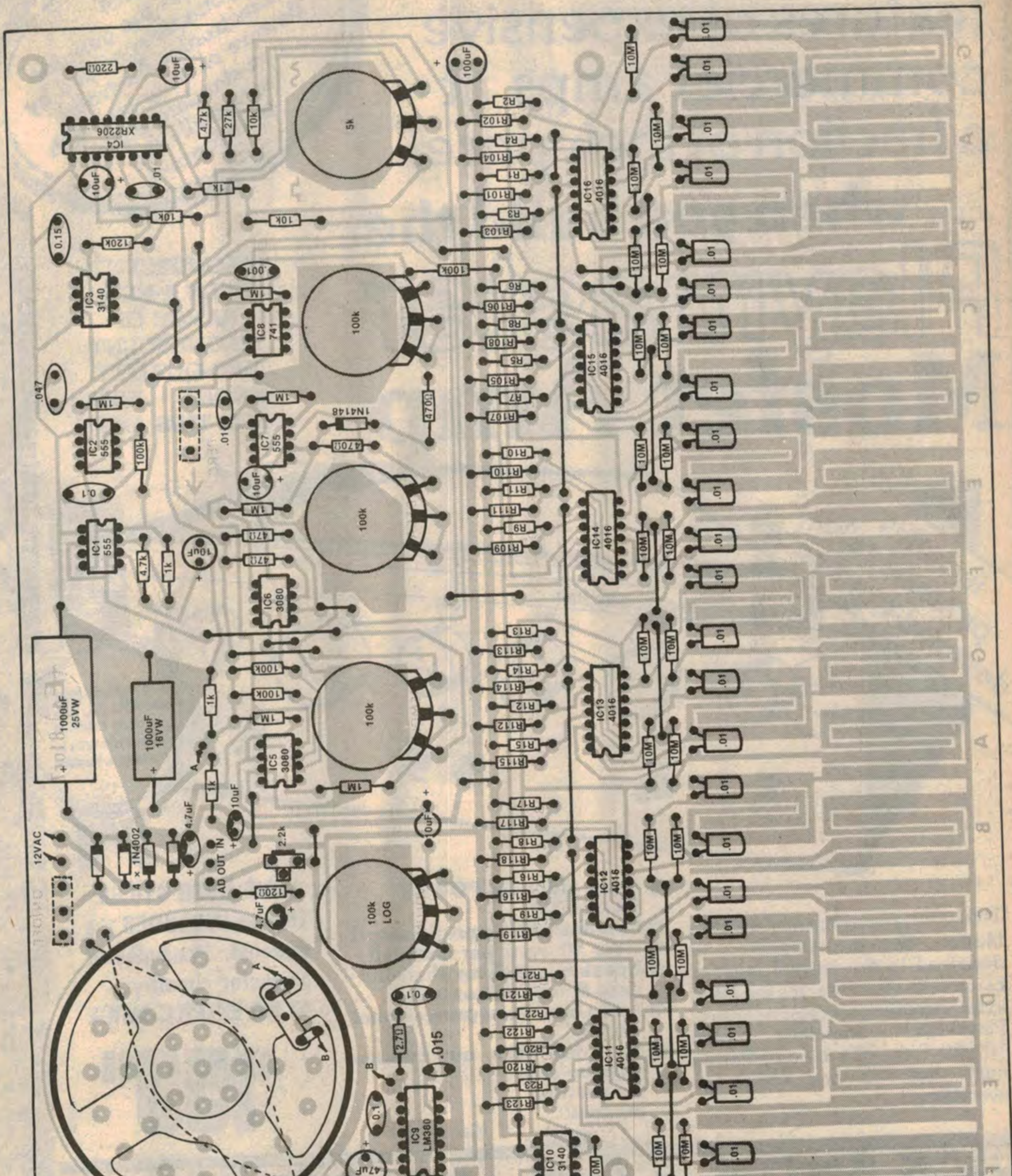
R1	22kΩ	R112	120kΩ//680kΩ
R101	91kΩ	R13	15kΩ
R2	22kΩ	R113	120kΩ//680kΩ
R102	110kΩ//680kΩ	R14	13kΩ
R3	22kΩ	R114	110kΩ//680kΩ
R103	110kΩ//750kΩ	R15	13kΩ
R4	22kΩ	R115	120kΩ//680kΩ
R104	100kΩ	R16	12kΩ
R5	20kΩ	R116	120kΩ//820kΩ
R105	110kΩ//680kΩ	R17	11kΩ
R6	20kΩ	R117	130kΩ//560kΩ
R106	110kΩ//820kΩ	R18	10kΩ
R7	20kΩ	R118	130kΩ//620kΩ
R107	120kΩ//620kΩ	R19	10kΩ
R8	18kΩ	R119	150kΩ//750kΩ
R108	110kΩ//620kΩ	R20	10kΩ
R9	18kΩ	R120	180kΩ//820kΩ
R109	110kΩ//910kΩ	R21	10kΩ
R10	18kΩ	R121	240kΩ//680kΩ
R110	120kΩ//750kΩ	R22	9.1kΩ
R11	16kΩ	R122	360kΩ//560kΩ
R111	110kΩ//750kΩ	R23	9.1kΩ
R12	16kΩ	R123	330kΩ

We estimate that the current cost of parts for this project is approximately

$68

This includes sales tax and the AC plug pack.

Electrochune keyless organ



Building the "Electrochune" is easy – just follow this wiring diagram. Note that the ON/OFF and PERCUSSION switches are mounted on the copper side of the board. IC sockets are optional.

provide decoupled reference voltage for the various op amps. Decoupling is provided by a 1000μF capacitor which also carries the loudspeaker return current.

CONSTRUCTION

As mentioned previously, all the components are accommodated on a large PC board measuring 249 x 210mm and coded 81or7. While our prototype had a gold flash over it for corrosion protection, we understand that production PC boards will be tin-plated. This will provide the same corrosion protection and also make it easy to solder.

Start assembly by making sure the holes are drilled to suit the potentiometers and slider switches used. Solder in all the links (use tinned copper wire) keeping them straight and tight between the mounting holes.

Next all the resistors can be soldered in place. Note that R1/R101 to R23/R123, whose values are depicted in the accompanying table have some parallel resistor combinations. These are mounted on both sides of the PC board. The resistors on the copper side are soldered directly over the opposing resistor and on the same mounting holes.

Now the ICs can be soldered in place making sure the orientation is correct. Note that not all the ICs are oriented in the same direction. The CMOS ICs should be soldered in place last, making sure that the supply pins (pins 7 and 14) are soldered first using an earthed soldering iron.

The capacitors can then be connected in place. We soldered the 23 .01μF capacitors for the keyboard 3-4mm above the PC board such that they could be bent over flush with the PC board. This prevents them from being broken off and gives a neater appearance.

The potentiometers are bolted to the PC board in their respective holes, and the terminals of these soldered directly to the PC board. The solder lug eyelet of each terminal will need to be cut off and the whole terminal bent through 180° in order for this to be achieved.

The loudspeaker is mounted face down on the fibreglass side of the PC board. Two lengths of stiff tinned copper wire are then soldered across the back of the loudspeaker from one side to the

PARTS LIST

1 printed circuit board, code 81or7, 248 x 200mm
3 100kΩ linear potentiometers
1 100kΩ logarithmic potentiometer
1 5kΩ linear potentiometer
2 SPDT slider switches
1 65mm loudspeaker
1 AC plug pack 12VAC 500mA

SEMICONDUCTORS
1 XR-2206 monolithic function generator
2 CA3140 BiMOS operational amplifiers
1 741 operational amplifier
2 CA3080 operational amplifier
1 LM380 audio power amplifier (14 pin DIL)
3 555 timers
6 4016, 4066 quad bilateral switches
1 LM317 three terminal regulator
1 1N4148 small signal switching diode
4 1N4002 1A rectifier diodes

CAPACITORS
1 1000μF 25VW axial lead electrolytic
1 1000μF 16VW axial lead electrolytic
1 100μF 16VW PC electrolytic
1 47μF 16VW PC electrolytic
6 10μF 16VW electrolytic
1 10μF 16VW tantalum
1 4.7μF 25VW tantalum
1 4.7μF 16VW tantalum
1 0.15μF metallised polyester
3 0.1μF metallised polyester
1 .047μF metallised polyester
1 .015μF metallised polyester
25 .01μF metallised polyester
1 .001μF metallised polyester

RESISTORS (5% tolerance, ¼W)
24 x 10MΩ, 6 x 1MΩ, 1 x 120kΩ, 4 x 100kΩ, 1 x 27kΩ, 3 x 10kΩ, 2 x 4.7kΩ, 4 x 1kΩ, 2 x 470Ω, 1 x 220Ω, 1 x 120Ω, 2 x 47Ω, 1 x 2.7Ω, 1 x 2.2kΩ miniature vertical trimpot.

RESISTORS (5% tolerance, E24 series)
1 x 910kΩ, 3 x 820kΩ, 4 x 750kΩ, 7 x 680kΩ, 3 x 620kΩ, 2 x 560kΩ, 1 x 360kΩ, 1 x 330kΩ, 1 x 240kΩ, 1 x 180kΩ, 1 x 150kΩ, 2 x 130kΩ, 6 x 120kΩ, 7 x 110kΩ, 1 x 100kΩ, 1 x 91kΩ, 4 x 22kΩ, 3 x 20kΩ, 3 x 18kΩ, 2 x 16kΩ, 1 x 15kΩ, 2 x 13kΩ, 1 x 12kΩ, 1 x 11kΩ, 4 x 10kΩ, 2 x 9.1kΩ.

MISCELLANEOUS
Tinned copper wire, solder, hook-up wire etc.

NOTE: Components specified are those used in the prototype. In general components of higher voltage and/or wattage ratings can be used providing they are physically compatible.

other and hold it tightly to the PC board.

Finally the wires can be brought to the loudspeaker and the slide switches soldered to the PC board. Note that the switches are soldered on the copper side of the board, and not the fibreglass side as would normally be the case.

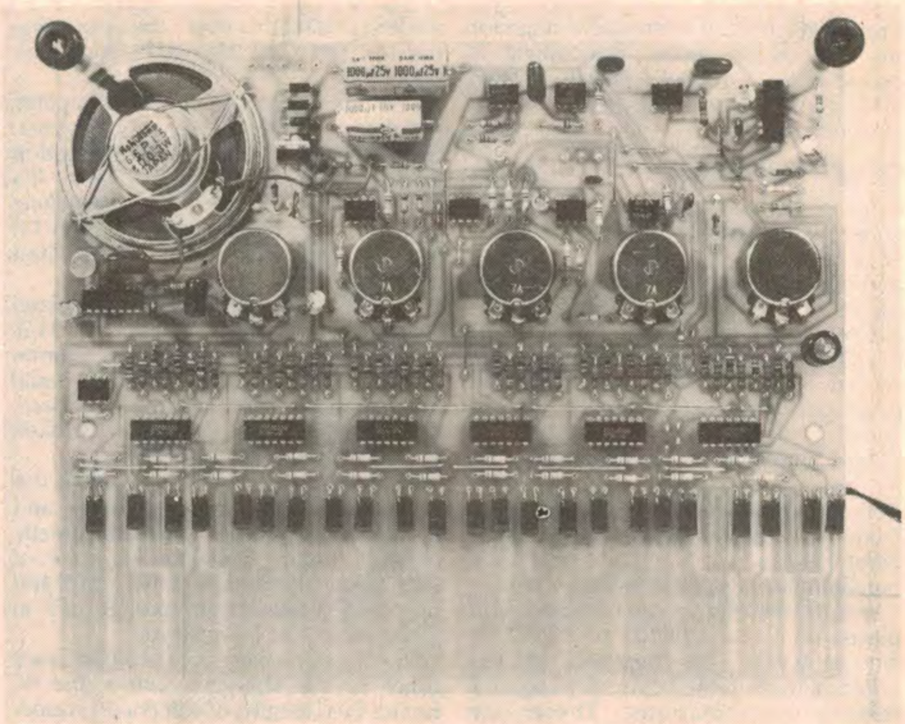
As far as tuning is concerned, we have attempted to make this as simple as possible. By using the values specified, the organ should be in reasonable tune. However, the overall tune would depend upon the voltage provided by the regulator being set close to 12 volts and the capacitor used for the oscillator on IC2.

For critical tune applications, the organ can be adjusted with the aid of a frequency meter or organ tuning standard. The frequencies for each note are given in the accompanying table for frequency meter use, but for the tuning reference methos, beats can be listened for or Lissajous figures set up on an oscilloscope. Various parallel resistors can be placed across the reference resistors, R1/R101 to R23/R123, until the instrument is in tune.

Note that the order of tuning resistors does not exactly follow the keyboard note order, but the relevant resistors for each note are labelled on the PC board overlay diagram for easy identification.

If you wish to make the Electrochune tunable to match other instruments, it will be necessary to have a variable capacitor in parallel with C1, which is connected between pins 5 and 6 of IC4, the VCO. The largest suitable variable capacitor we know is the solid dielectric type used in most portable AM radios. These normally have a range of several hundred picofarads, giving a useful tuning range.

Note that if you wish to make use of this option, you will have to make sure that, when the variable capacitor is in circuit, the Electrochune can be brought to standard tune, ie A at 440Hz. The same remark applies if you wish to tune the whole instrument precisely, as described above: first make sure that you have a precise 12 volts from the regulator and then set A440 by suitable adjustment (ie, padding with small parallel capacitors if necessary) of C1.



The completed prototype. Note that some tuning resistors are also soldered to the copper side of the printed circuit board (see photo p52 and table p56).

Playing the Electrochune involves the use of one finger only. If a second finger contacts another note while the first finger remains on a key the same note will still play. It is not until all fingers are released from the keyboard that another note can be played.

From time to time it will be necessary to clean off the keyboard (with a weak detergent solution) so that any build-up of grease and dirt does not prejudice operation by tending to turn on the CMOS keys. Do not use abrasive cleaners for this job.

The Attack and Decay controls are adjustable from about .005 seconds to about one second, giving rise and fall envelope times varying from almost instant to a slow rise time. Note that if the percussion is on with maximum attack and decay times, then just a "plop" will be heard. With the percussion off, the note will appear to respond only when the key is pressed.

Next month we hope to publish constructional details of a suitable cabinet for the Electrochune, together with a label for the controls.