IC's for electronic music

Electronic music is a fast-growing field with the synthesizer arousing the most interest among the avant-garde. Regardless of what you want in electronic music, IC's will simplify design and ease construction.

SUPPOSE YOU WERE GOING TO DESIGN AND build an electronic music synthesizer, a pitch reference, an electronic organ, a composer, a timbre generator, or some entirely new instrument. What devices would you use? Where would you go for help?

While there are a few integrated circuits that are obviously and specifically intended for music use, these are rare, usually expensive in small quantities, and often hard to impossible to get. On the other hand, there are great heaping piles of different IC's available that don't even hint they are good for music use. These, or at least some of them, are widely available, cheap, and, best of all, many of the latest dramatically simplify things, doing as good and sometimes much better a job than older circuits did. In fact, some circuits are now available that are almost hard to believe—a very stable sine, square, triangle VCO for $3, a *hex* voltage-controlled amplifier for $1.80; a tracking "glider" phase-lock-loop that works over a 2000:1 frequency range without harmonic locking and costs under $5; a *single IC* to generate all the equally tempered notes of one octave; and switches that handle analog or digital, one to N or N to one reversibly, for under $2.

Here's my selection of a few dozen or so integrated circuits that are (1) cheap, (2) widely available, (3) applicable to electronic music, and (4) do a job far simpler or cheaper than older approaches. Table I lists all the manufacturers and their addresses. All prices are approximate. Be sure to have good data sheets and application notes on hand before you try to use *any* integrated circuit.

One IC top octave generator

Most music is arranged into twelve-note *equally tempered* note groupings (take a look at a piano keyboard). As you go up in frequency one *octave*, you double frequency on the *thirteenth* note. The note spacing is NOT linear, it is exponantial. Each note is spaced from its neighbor by $\sqrt[12]{2}$ or approximately 6%. There is no reasonable way to exactly generate anirrational number such as $\sqrt[12]{2}$, so you have to *approximate* it the best way you can. Usually you start with a 1 or 2 *megahertz* crystal and then divide down by some "magic" optimum series of numbers (often 239 - 253 - 268 - 284 - 301 - 319 - 338 - 358 - 379 - 402 - 426 - 451) to get a good enough approximation to the highest octave you care to generate. From here you pick up the rest of the notes with a simple string of binary dividers.

The circuitry that handles the top octave is called a *top-octave generator*. Many of these circuits had been based on the GEM555 and GEM556 a pair of hard-to-use, harder-to-get IC's that are now essentially obsolete.

The *Mostek* MK5024P/AA is a one-chip,

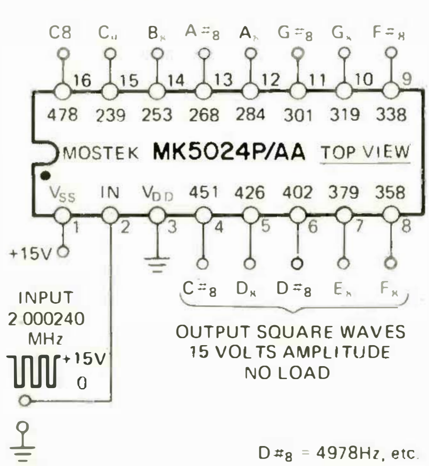
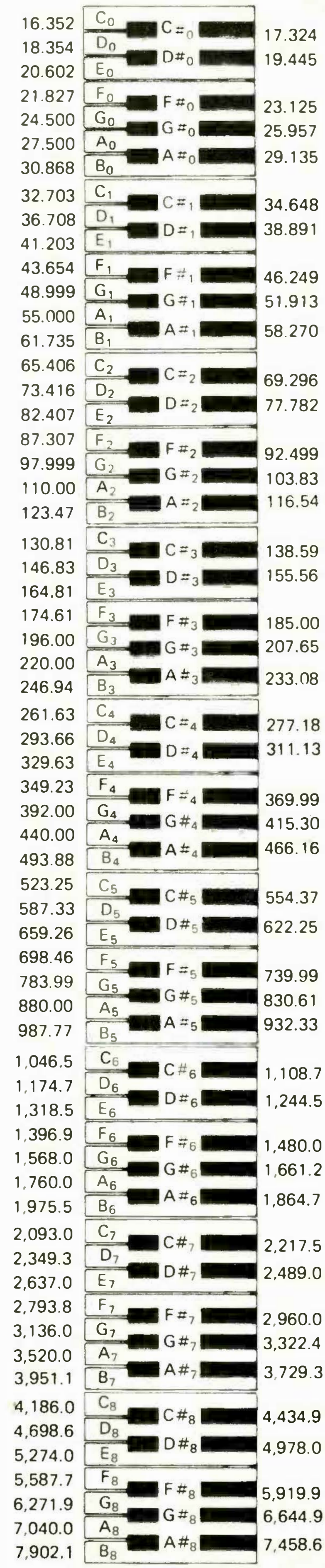


FIG. 1—SINGLE IC top octave synthesizer.



single 15-volt supply top-octave generator. Hook it up as in Fig. 1. You input a 2.000240 megahertz squarewave or sinewave of 15 volts amplitude, obtained from a crystal oscillator (for permanent tuning) or a variable oscillator (for vibrato, glides, or tuning to another instrument). You get thirteen outputs, appearing as square waves from C8 at 4186.01 hertz to C9 at 8369.2 hertz. Cost is under $12. This is admittedly a bit steep, but it is by far the cheapest route to go if you want all the notes at once.

If you only want one octave at a time, you can place a single binary divider between the oscillator and the top octave generator, rather than using 12 separate dividers.

Seven octaves at once

Once you have the top octave, you add binary dividers to get the rest. Again, there are several "music-only" divider IC's available, but none is as good, as easy to use, or as cheap as the RCA CD4024 or Motorola MC14024 CMOS 7-stage dividers. Cost is around $3.50. One IC is needed to produce seven octaves of a single note. Thus a top octave generator IC and twelve of the CD4024's will generate simultaneously all eight octaves or a total of 97 notes.

Figure 2 shows the connections. Simply apply a voltage from +3 to +18 (best results

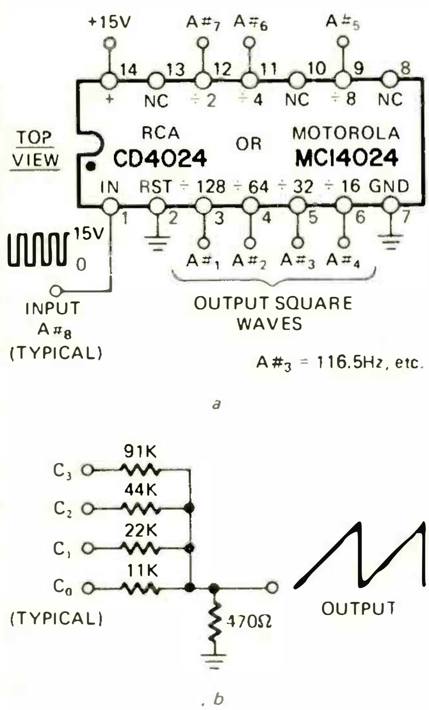


FIG. 2—DIVIDE BY 128 provides lower octaves for any note. a—Circuit for square waves. b—Adding resistors for sawtooth.

with +15) and input the top octave output. You get out seven new notes in octave steps. For instance, input A#8 (A sharp, 8th octave), and you get out A #7, A#6, A#5, A#4, A#3, A#2, and A#1. The outputs will all be square waves. Square waves only have odd harmonics present. You can convert these to sawtooth waveforms with virtually all harmonics present with a few resistors as shown as in Fig. 2-b. While the stairstep may not *look* quite like a sawtooth, analyze it and you'll find the first missing harmonic is the 16th, followed by the 32nd and the 48th, etc. . . . Otherwise it is absolutely identical to a linear ramp. Filtering is used to convert either the square or sawtooth outputs into familiar tone colors. For instance, the square waves are often used for clarinet and stopped organ sounds; the sawtooth by itself has a good string sound, while bandpass filtering is easily added to a sawtooth to get a horn or reed output.

A tempo generator

How do you get a stable, cheap, wide-range square wave oscillator that's good enough as a monophonic note generator, but also is useful for rhythm and clocking, and easily drives TTL and CMOS to boot? With the *Signetics* 555 or *Motorola* MC1555 of course. This $1 IC can't be beat as a stable oscillator. Figure 3-a shows details. You can vary the resistance from 1K to 3.3 megohms, and make the capacitance anything you want above 500 pF or so. Output is usually a rectangular wave. If you need a square wave, make R2 much bigger than R1 or else add a binary divider to square it up. Figure 3-b shows how you can build a triggerable monostable or pulse generator out of the same circuit. This is useful for synthesizer envelope generation.

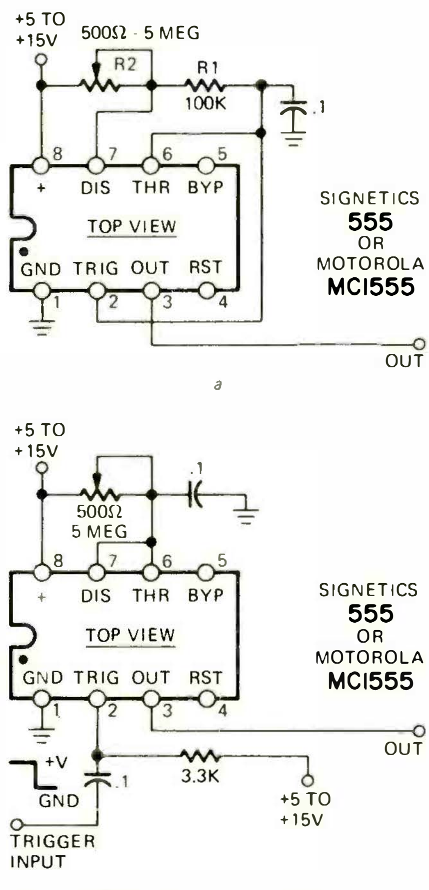


FIG. 3—USING THE 555. a—Astable, or rectangular wave generator. b—Monostable or pulse width generator.

A voltage-controlled oscillator

Many synthesizer systems are based on *voltage controlled oscillators*. Apply an input or control voltage, and you get an output frequency which you use as a tone source. Music VCO's have to be very stable to be useful. They also have to have a wide range. Ideally, they should respond in a log manner, but a log converter is more often added to the input of the VCO as a separate circuit. VCO's also should be able to put out a good looking sinewave for flute-like tones, as well as a square or triangle output. The *Intersil* 8038 does the whole job for under $3. A "baseline" circuit is shown in Fig. 4 that should get you started. Control voltage ranges from the positive supply to three volts or so *less*. The sinewave can be adjusted to below 0.5% distortion easily.

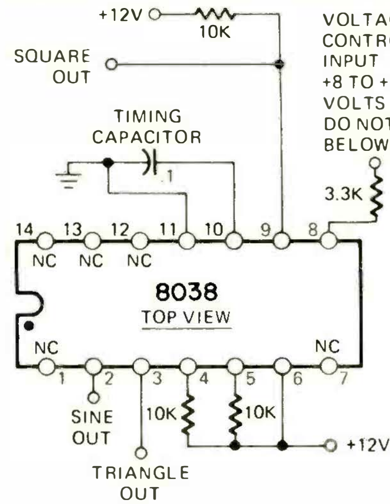


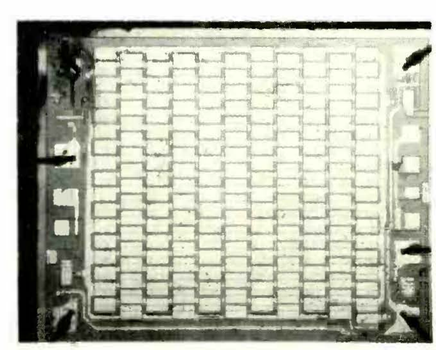
FIG. 4—SIMPLE VCO using Intersil 8038.

A dual operational amplifier

A good "741" style op-amp is essential for any electronic music circuit. An operational amplifier does at least three good things for you—it gives you controllable gain; it eliminates interaction and coupling between multiple inputs; and it gives you a versatile system gain block for active bandpass filters and things like this.

The *Motorola* MC1458 and the *Signetics* 5558 are typical dual "741" type circuits. Cost is around a dollar. The 5558 is in an easy-to-use 8-pin minidip package.

Figure 5-a shows the voltage follower connection. It gives you unity gain, a very high input impedance, a low output impedance and does not invert the signal. Figure 5-b is a voltage follower with gain. Figure 5-c shows the inverting amplifier and mixer. The gain of each input is the ratio of its own input resistor to the feedback resistor. The input impedance equals the input resistor for any input, and the summing point may be considered to be a *virtual ground*. There is no interaction between inputs or crosstalk problems possible in this circuit; further, you can *scale* or individually adjust each and every input to its own signal level inde-



ITT TCA350 ANALOG SHIFT REGISTER is 185-stage bucket-brigade af delay line.

pendently, while the feedback resistor can be varied as a master gain control. Figure 5-d shows a good, high-Q bandpass filter circuit you can use to independently control

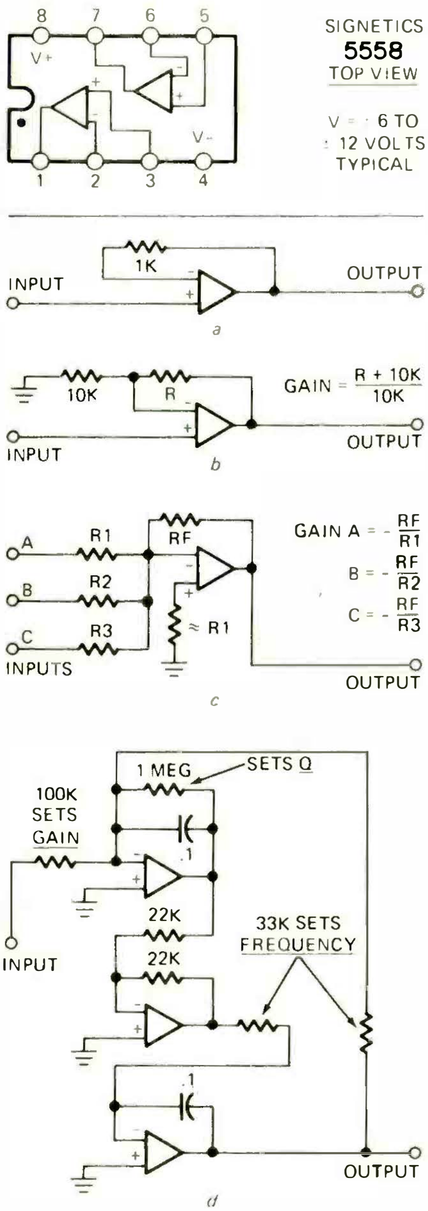


FIG. 5—A DUAL 741 STYLE OP AMP. a—voltage follower (high input Z, noninverting). b—Voltage follower with gain (high input Z, non inverting). c—Current summer or mixer input is at virtual ground, no crosstalk is possible). d—High-Q bandpass filter.

the Q (to 500!), the gain, and the center frequency on. Use this for formant voicing circuits, sinewave recovery, and anywhere else you might like to emphasize a narrow frequency band.

By the way, if you are working at high frequency and high gain, the 741 style devices might not have enough bandwidth to do the job. If you need only a little bit more, try the Motorola MC1741S; for a whole bunch more bandwidth, go to the more expensive *National* LM318.

Six keyers at once

At the very least, music notes must be smoothly turned off and on without any key clicks or thumps. It's even better to be able to instantly vary the gain of the note so you can have complete control of attack, fallback, sustain, decay, snubbing, and perhaps even an echo. To do this, you need something that will behave as an electrically variable resistor. The circuit is called a *keyer*, an *analog gate*, or a *voltage-controlled amplifier*.

There are lots of bad ways to do this job. What you have is some circuit that is essentially *transparent* to the notes fed through it—it simply varies gain and nothing more. You must control the gain smoothly and do so equally well on the positive and negative portions of the envelope. Above all, you cannot let any portion of the envelope or control signal appear as an output, for this gives you a loud thumping.

Diodes have traditionally been used in organ circuits, but they thump, introduce distortion, and have a limited dynamic range.

An obvious choice is an integrated circuit four-quadrant multiplier—see below—, but these are far too expensive to use dozens at a time. Another possibility is an electronically controlled gain block such as the *Motorola* MFC6040, but it has too much gain for many applications.

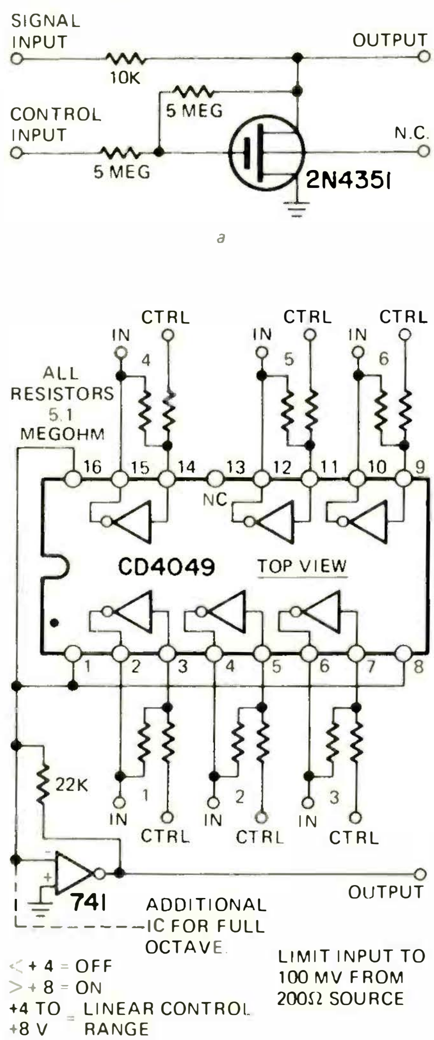


FIG. 6—HIGH-QUALITY HIGH-PERFORMANCE hex keyer or VCA costs only 30¢ per note. a—n-channel transistor as electrically variable gain control or keyer. b—CD4049 converted to six n-channel transistors.

The simplest *good* envelope keyer you can use is a single N-channel MOS transistor with some drain-to-gate feedback resistance. Figure 6-a shows the circuit. This gives you a linearly variable resistor, electronically controllable, and smoothly handles up to 10 volts of analog signal in either direction if the substrate lead is floated. Control voltage ranges from 4 or less for full off, up to 8 or more for full on; in between you get a good linear control range. For envelope and audio frequencies, there is absolutely zero feedthrough of the control signal. As a bonus, the control input looks into a high impedance that lets you use a small capacitor for the decay portion of the cycle. One typical discrete device is the *Motorola* 2N4351. At $2 or so, the cost is far cheaper than a multiplier, but still a bit steep if you use 97 of them at once.

Once again, it's digital CMOS logic to the rescue. A very few CMOS IC's can have their supply shorted to ground and thus disabling all the P-type transistors in the package. This leaves you with a block of N-channel MOS transistors that are ideal for gain control. You can get two and possibly three in the CD4007 (RCA) or the MC14007 (Motorola) devices in a dollar package. Most of the other devices, particularly the CD4009 and CD4010, have protective diodes arranged in such a way that you can't do this. The diodes are differently arranged in a new device—CD4049 (RCA) and MC14049 (Motorola). With this package, you get *six* voltage controlled amplifiers in a single integrated circuit. Cost now is around 35¢ per amplifier, but this will drop to around 10¢ per amplifer shortly.

Figure 6-b shows a full proportional control system with complete, thump free, control of attack, sustain, and decay.

Note that in both circuits, the package *ground* and *positive* terminals are tied *together* and form the *output*. The traditional inverter "outputs" are the signal or timbre input and the traditional inverter "inputs" receive the envelope commands. 3 volts or less is off; above 6 volts is on; in-between you get a smooth control range. Best input signals are less than 100 millivolts high and from a 300-ohm or less source impedance. The op-amp builds this back up to a volt or two output, eliminates crosstalk, and prevents negative feedback from reaching the gate circuit.

An analog quad switch and sample-hold

While you are looking at CMOS, check out the RCA CD4016 or the Motorola MC14016. Either of these has four separate analog off-on switches that you can apply up to ten volts of peak-to-peak signal to. You use the same circuit digitally, frontwards as a one line to four line distributor, backwards as a four line to one line selector, or as four separate switches. Unlike virtually all other IC logic families, the signals can go through the switch in *either* direction.

Figure 7-a shows the IC. Figure 7-b is a digital or analog one-to-four distributor. Figure 7-c is a digital or analog four-to-one selector. Finally Fig. 7-d shows how you can build a *sample-hold* amplifier with one quarter of this package, a good Mylar capacitor, and an operational amplifier. Sample-holds are useful in synthesizers for remembering what frequency a note was after a key is released so the decay cycle can

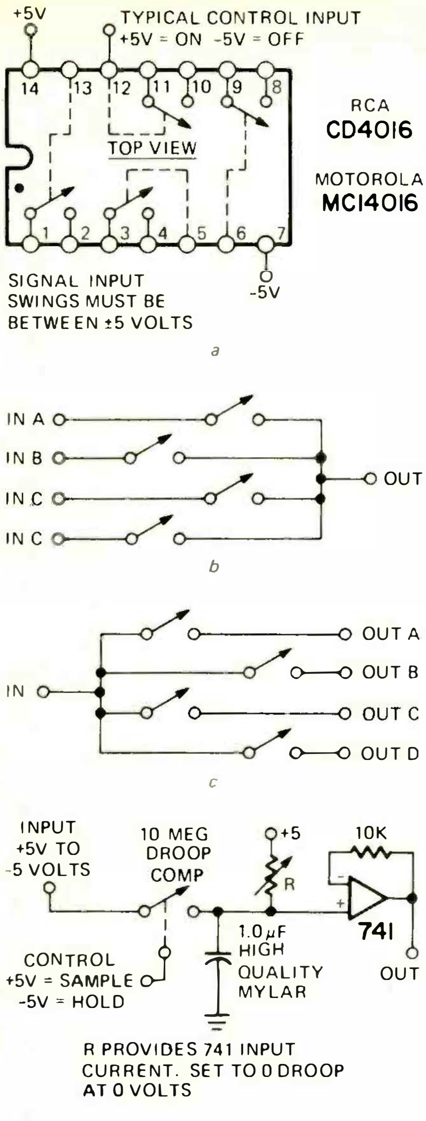


FIG. 7—A DIGITAL OR ANALOG quad switch. a—Circuit. b—Data selector—analog or digital. c—Data distributor—analog or digital. d—Low cost sample-hold.

be completed. The 4016 costs around $1.50. A complete sample-hold can be built for less than a dollar, since you need ¼ of this package, ½ of a dual op-amp and a capacitor. As with other CMOS circuits, the input control signal works into an open circuit. −5V is OFF; +5V is ON.

A tracker or gliding VCO

One of the biggest problems in any synthesizer is doing glides, sweeps, and trombone effects on a keyboard instrument. A circuit originally used by Olsen in the pioneer RCA synthesizer work to do this was called a *glider*. Today, it's called a phase-lock-loop tracker, and it is available as the RCA CD4046 or Motorola MC14046.

What the circuit does is this. You send it a frequency. It grabs onto that frequency from the one it is already at. You can control *how fast* the grabbing takes place. It can be nearly instantaneous, or it can provide a glide or sweep.

The circuit has an internal oscillator that compares its frequency against an input and then provides an error correction signal. You add a capacitor to slow down the response time to "errors".

Now, there're bunches of phase-lock loops available and you probably have already tried a few. The hangup here is that the IC you use must have at least a 1000:1 voltage controlled frequency range and must *NOT* be harmonic sensitive. This leaves out everybody but the MC4046. (The usual "565" type of PLL has only a 3:1 frequency range and is harmonic sensitive.)

One experimental circuit is shown in Fig. 8. Your input frequency can be a sine, square, or triangle or sawtooth wave. If you

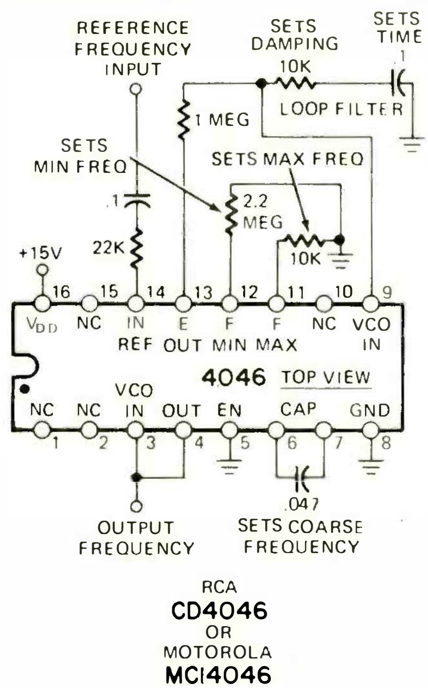


FIG. 8—PHASE-LOCK-LOOP tracker does glides and portamento from keyboard control.

are trying to follow a more complex waveform, filter it *thoroughly* to recover mostly the fundamental, or use a comparator circuit for conditioning. The capacitor sets the glide time, while the bottom resistor sets the *damping* or the overshoot. Make this resistor too *small*, and you get wild "Bounce" effects.

Cost is under $5. The normal output is a square wave, but you can easily break the loop and put in a binary divider and sawteeth resistors. You can also divide the input as well, perhaps to follow a fifth above or below, an octave above, and so on. The potential is fantastic. Use several together for chorus effects. Add external "noise" to the error signal for vibrato, chorus, or randomness.

And some others . . .

Let's take a quick look at a bunch of other devices that you may want to use in music circuits. These are a bit more specialized, but can solve some unusual music problems fast:

Motorola MC1408-6 and MC1408-8. Six and Eight-Bit Digital to Analog Converters. Input a digital sequence and get notes out. Multiplying but not truly bilateral. An output amplifier is needed. Under $5.

American Microsystems Inc. has a whole line of MOS music products. These include older top octave systems, rhythm generators, rhythm counters, and newer devices that combine functions. The S2566 Rhythm Generator provides a complete handbox-on-a-chip when combined with a counter. Around $18.

Analog Multipliers. Analog multipliers are true four quadrant multipliers. They can be used for precision keyer and VCA applications or for *ring modulators*, where you combine two tones and get only the sum and difference out, or where you shift the frequency of a tone to compress or expand its harmonic spectra. These are still a bit steep in price to use on each and every note, but in a synthesizer system, one or two of them is certainly worth the price. Costs run from $15 upwards. Typical devices are the *Motorola MC1494* and *MC1495*, the *Signetics* 5596, and the *Analog Devices* AD532J.

Besides the CMOS we've talked about, check out the plain old CD4001 (MC14001) quad gate. What better way to expand the contacts on a keyboard for coupling, translation, and transposition. It takes three IC's per new contact per octave, or ¼th of an IC per contact per key. It's the cheapest CMOS device, well under a dollar surplus.

—*by Don Lancaster*

TABLE 1
Some Manufacturers

(Be sure and specify *specific* devices; the majority of these circuits were designed for *non-music* applications.)

AMERICAN MICROSYSTEMS INC. 3800 Homestead Road Santa, Clara, Calif. 95051	MOTOROLA SEMICONDUCTOR Box 20912 Phoenix, Ariz. 85036
ANALOG DEVICES Norwood, Mass. 02062	NATIONAL SEMICONDUCTOR 2900 Semiconductor Drive Santa Clara, Calif 95051
INTERSIL MEMORY CORPORATION 10900 North Tantau Avenue Cupertine, Calif. 95014	RCA SOLID STATE Box 3200 Somerville, N.J. 08876
ITT SEMICONDUCTOR 3301 Electronics Way Palm Beach, Fla. 33407	SIGNETICS 811 East Arques Avenue Sunnyvale, Calif. 94086
MOSTEK INC. 1215 West Crosby Road Carrollton, Tex. 75006	TEXAS INSTRUMENTS PO Box 5012 Dallas, Tex. 75222