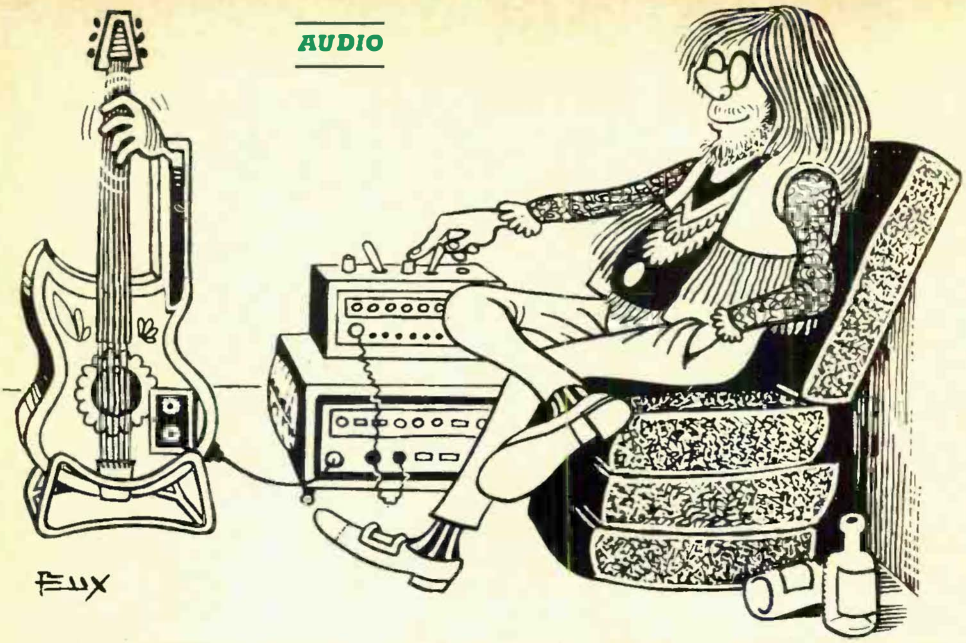

PITCH GENERATORS for ELECTRONIC MUSIC

PART 1. SEPARATE VOICING AND VCO WITH SAMPLE-HOLD GENERATE NOTES ELECTRONICALLY

BY DON LANCASTER

LAST MONTH ("Electronic Music Pitch Standards") we discussed the frequencies wanted and stability needed in designing a useful electronic music pitch generator. In most cases, the equally tempered scale would be used, usually based on twelve notes per octave with each successive note 1.0595 (the twelfth root of 2) times higher in frequency than its neighbor below. To accompany some conventional musical instruments, it would probably be necessary to set the absolute pitch of A4 to 440.0 hertz. The overall stability should be within three cents of the desired pitch—one cent or better, if possible. (One-cent frequency stability is about 0.06% or 600 parts per million.)

The problem now is to determine what hardware should be used to generate all these notes; and the first thing to decide is whether or not more than one note at a time is needed. When working in a studio, with an elaborate tape recording setup, or when teaching or learning musical theory, the flexibility of the monophonic or single-note systems can be a tremendous advantage. This is particularly true when it comes to envelope generation and special effects involving the interaction with time of pitch, timbre, and envelope. When playing along with other instruments, single notes might not be too bad—particularly if the voicing is unique or is a stunning imitation of some classical instrument.

About half of the single instruments generate only one tone at a time (trumpets, clarinets, trombones, etc), while the remainder (organs, pianos, guitars, violins, etc.) can and do generate more than one (or overlapping) notes at a time. The kicker here is that we rarely listen to just one single-voiced instrument. For instance, have you heard any good bassoon solos lately?

At this stage of the music game, the single-voiced monophonic circuits offer flexibility and low cost but are pretty much limited to the tape studio or to use with

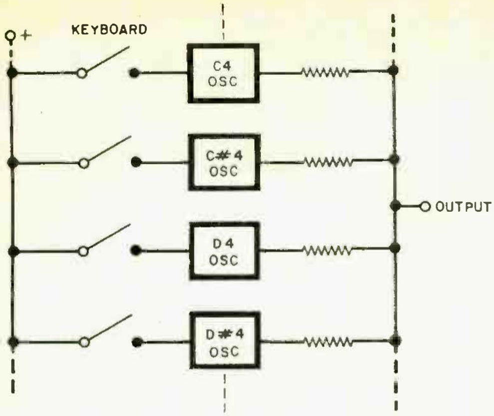

Fig. 1. Keying each oscillator individually is simple and eliminates crosstalk problems, but limits envelope characteristics.

other instrument ensembles. If the electronic music synthesizer is to stand by itself or be used in live concerts, then polyphonic, or multiple voicing is very desirable—almost essential. (An instrument with both polyphonic and monophonic capabilities is an interesting possiblity, but more on that later.)

Another decision to be made is whether or not rock-stable notes are always needed. For many voices of medium pitch, the addition of vibrato or frequency modulation adds an interesting and potentially realistic quality to the tone. On the other hand, vibrato sounds very phony on notes of lower pitch, particularly in imitating organ pipes. (Vibrato can be introduced after the pitch is generated by phase-modulation or analog-delay effects.)

By rocking the pitch around a little, we can tune to match other instruments and achieve special effects such as the waa-waa of a Hawaiian guitar. To really move the notes around (as on a slide trombone), a portamento or glide capability is necessary.

Probably the best compromise is a stable reference system that can easily be adjusted in frequency, but which will readily return to absolute pitch on command. From a usage standpoint, either no pitch adjustments, one main adjustment, or a circuit that is exceptionally stable is wanted. One other reason for changing pitch is for transposition—playing in a different key.

With these basic needs in mind, we will consider four popular ways of generating pitch electronically: separate voicing; **vco** (voltage-controlled oscillator) and sample hold; digital divider; and phase locked loop tracker. The first two are covered in this article; the last two next month.

Separate Voicing. In this type of pitch generation, an individual oscillator is used for each and every note and power is applied to only one oscillator at a time (Fig. 1); or a separate keyer is used for each note (Fig. 2). The first method has the advantages of using only dc voltage through the keyboard and the elimination of crosstalk since all the unused notes are off. Its disadvantages are that it is limited to very simple attack-sustain-decay shaping and it requires exceptionally good frequency-vs-supply-voltage performance during the rise and fall times.

Tuning is obviously difficult since one adjustment is needed for each oscillator. Free-running astable relaxation oscillators have traditionally been far too unstable for this sort of thing. So large inductors and Mylar capacitors were normally used in Hartley or Colpitts oscillators, with amplitudes held low enough that the active devices didn't cause serious problems. Typically, capacitor bridging was used for coarse tuning with a potentiometer for final adjustment.

With today's latest IC's, such as the Intersil 8038, it is possible to design a relaxation oscillator with a stability of 50 parts per million—eleven times better than needed—and it produces vibrato easily. This eliminates the need for the inductor and

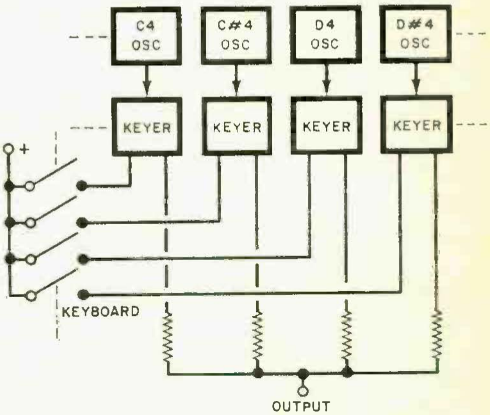

Fig. 2. Separate keying offers more flexible envelope control but adds complexity.

greatly eases tuning, but it still leaves a complex and expensive tone generation method.

The one place where separate voicing really shines is in faithful duplication of organ pipe ranks, particularly tibias, where a nearly perfect analog of the traditional pipe organ can be obtained with enough care. For any other system, the large number of parts and difficulty of tuning make the newer methods more attractive. Also, this approach is obviously polyphonic, and portamento is not easily introduced.

The VCO and Sample-Hold. The voltage-controlled oscillator (vco) pitch-generation technique is the one most often used today in "Moog-style" synthesizers. It is monophonic by itself, but there are tricks that can be played with the keyboard to get a two-note capability with a second vco and moderate additional complexity.

Figure 3 shows the vco technique. A vco produces a specified pitch in exchange for a fixed input voltage.

If a *linear* vco is used, the frequency output is linearly related to the input voltage, and the control or input voltage gets rather cramped at the low end where all the low notes have to be close together. This takes odd-ball precision or paralleled resistors of different values. It also severely restricts the stability and linearity of the vco.

A much better, but slightly more complicated, method is shown in Fig. 4. Here a logarithmic converter is used in front of the vco. A log converter exactly matches the ear's response capability, so a linear input can be used to generate the notes properly spread apart. For instance, a one-volt-per-octave system can be used, so that note C3 might require 3 volts, C4 would need 4 volts, and so on. This means a linear increase of $^1/_{12}$ volt for each successive note on the scale.

The log converter then automatically spaces out the notes to get the right frequency separation. One popular type of log converter places a pn junction in the feedback loop of an op amp. The junction has the required logarithmic characteristic. Usually, a pair of matched transistors is used, with the second transistor handling offset and temperature problems.

With the log converter, it is still necessary to have precision resistors on the keyboard, but they are all identical. Usually, the keyboard is driven by a constant-current source, and a selected number of series-connected resistors is shorted. The remaining voltage drop then equals the voltage needed for the note. This voltage is properly changed to a new voltage by the log converter; and the new voltage is converted to a frequency by the vco.

The basic vco method is low in cost, but it is single-voiced and extreme stability is needed for the keyboard controller, the log converter, and the vco. Pitch is easily changed by changing the current through the keyboard or the scale factor of the vco; and any number of notes per octave can be readily handled on a one-at-a-time basis.

One problem common to the vco and a number of the other single-voiced methods is the need for a memory of some sort. Whenever we release the key, we often would like the note to continue on and die out gradually. With the vco and log converter, releasing the key takes away the information (the input voltage) of what note is to be played. To overcome this, a sample-hold or analog storage system is added as shown in Fig. 4.

Pressing any key immediatly changes the sample-hold to a new note. After the key is released, the sample-hold remembers what the note was until the decay cycle is complete and a new note is generated. In this way, the decay cycle of the envelope shaping can continue beyond key release.

One simple sample-hold circuit is a reed relay and a capacitor looking into a voltage follower. The relay is closed for sampling and the capacitor then holds this value.

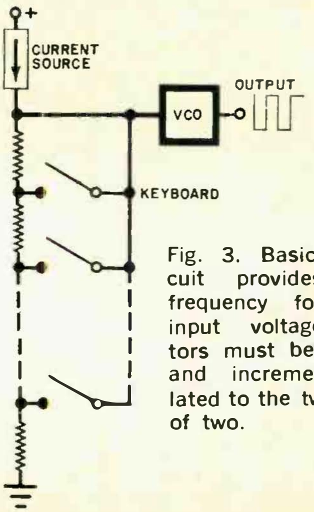

Fig. 3. Basic vco circuit provides output frequency for precise input voltage. Resistors must be precision and incrementally related to the twelfth root of two.

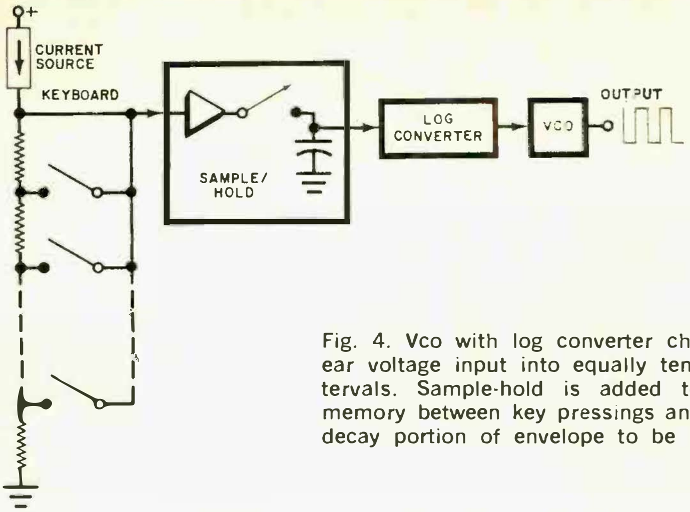

Fig. 4. Vco with log converter changes linear voltage input into equally tempered intervals. Sample-hold is added to provide memory between key pressings and to allow decay portion of envelope to be continued.

Other methods use an operational amplifier with a FET switch; or a CMOS analog multiplexer (such as the RCA CD4016) can be used directly.

The basic principle of most of the analog sample-hold circuits is to charge a capacitor rapidly when the key is pressed and then use the capacitor to hold the voltage as an analog memory after release. For the charge to be held without significant droop, a very high-quality capacitor and an absolute minimum of circuit loading are needed.

Glides and portamento effects are simply done by charging the capacitor somewhat more slowly. In this way, the notes glide from one to another in a trombone style rather than changing suddenly.

The major advantages of the vco system are the ease with which one can make glides, change pitch, introduce vibrato and waa-waa, or change the number of notes per octave. This approach can be used very inexpensively with the latest available components, but very careful attention to stability and accuracy is needed.

For instance, with a one-volt-per-octave control voltage, a voltage error, droop, offset, or crosstalk of only 2.5 millivolts will cause an objectionable pitch error. Extremely careful design is needed to get a good vco/log converter/sample-hold system going. On the other hand, this is certainly the simplest way to put together a low-cost system on an experimental basis. The results will be disappointing to a serious musician, however, if careful control and good design are not used.

Note-to-note tuning is inherent in the selection of the precision resistors on the keyboard, while overall instrument tuning is controlled by a single reference voltage or current and the stability of the rest of the circuits.

Using two vco's will provide two-note capability and more vco's can be added as needed. The problem that immediately comes up is, "Which vco goes with which note?" The answer is to use very brief sample-hold intervals and properly assign each key being pressed to the right vco. One possible way of doing this is with a *scanning* keyboard where each key being pressed is sampled in either digital or analog form; and priority logic then assigns the right vco to a selected key. This adds considerably to the cost and complexity of the system.

At present, the vco/log converter/sample-hold pitch generation approach is the most popular in commercial synthesizer products. This is, however, probably only a temporary stopping place along the way to total digital pitch generation systems. Voltage-controlled pitch generation systems will probably go the way of most other analog systems, but right now vco methods are attractive and offer a lot in the way of simplicity and low-cost performance.

Next month, we will discuss digital dividers and phase locked loop methods of tone generation ◆