COMPONENTS FOR ELECTRONIC MUSIC SYSTEMS

Tone generators, keyboards, and voicing techniques.

BY DON LANCASTER

ANY electronic musical instrument can be viewed from a systems standpoint. Many of the features common to electronic musical instruments are shown in the block diagram of Fig. 1. This instrument could be an electronic organ, a synthesizer, or a computer-type composer. For the moment, let's just consider it as a "system" and take a closer look.

All electronic musical instruments begin with a means for generating tones. Next comes control of the presence of the tones and the formation of the *envelope*, or attack/sustain/decay characteristic, of the note. This is followed by a suitable alteration of the tone's harmonic content to obtain a particular *voicing* that will make it more interesting to the ear. Finally, the tone is amplified and delivered to either a live audience or to a tape recorder. If desired, along the way, special effects like amplitude and frequency variations, noise, echo, transients, or spectrum translation can be thrown in.

Instruments that generate only one tone at a time are termed *monophonic*, while those that have a multiple-tone capability are called *polyphonic* instruments. Through the use of a tape recorder, complex tonal structures can be built up with a monophonic instrument, not on a real-time basis.

Tone Generation. Tones can be generated either through the use of digital or analog circuits. One possible analog system provides for a separate oscillator for every note and ideally for every *voicing*, or *timbre*, of every note. Another analog method employs a *voltage-controlled oscillator* (vco) that can be set to any desired tone simply by presetting the proper input voltage level. Besides being movable in pitch, this latter analog method offers an easy way to do glides and sweeps, vibrato (FM), and random variations in the produced tones.

One approach to digital tone generators starts with the needed notes at the upper end of the musical range. Twelve notes are used if the traditional equally tempered scale is desired, but as many as 31 notes per octave are sometimes used in modern compositions. Binary dividers then provide octave-related 2:1 frequencies, generating as many tones as are needed. Each flip-flop divides the input frequency exactly in half; the entire audio spectrum down to the low bass notes can be readily generated in this manner.

A modern refinement starts with a single crystal in the 2-MHz region and derives all of the upper division notes by repeated divisions. This results in a fixed-

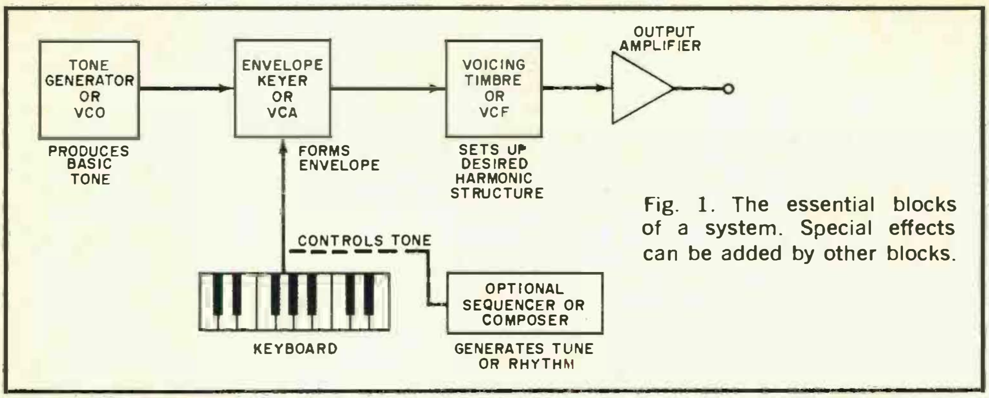


Fig. 1. The essential blocks of a system. Special effects can be added by other blocks.

tuned, permanently accurate instrument if crystal control is used. A single pitch adjustment is needed if a variable oscillator is used.

Another digital method starts with the 16th, 32nd, or 64th harmonic of the desired note. It then runs through a memory circuit that converts the harmonic samples of the note into an overall desired shape. At the same time, voicing is performed by the replication method. A final digital technique uses a computer or an elaborate memory and sequencer to perform all operations, specifying the voicing, tonal characteristics, frequency, and envelope simultaneously.

With most pitch systems, tones are generated in whatever waveshape is handy—usually a sine, square, or triangle wave. Occasionally, white or pink noise or some other structure is used. Only in the replication voicing systems does the generated tone look like what is ultimately desired. Simple sine, square, and sawtooth waves sound uninteresting. To give them color and appeal, voicing or timbre circuits are used.

Tone Controllers. Once tones are generated, a way is needed to control them so that only the notes wanted appear at the output. A keyboard is one type of on/off controller. Notes can also be digitally or computer controlled, in which case a *composer, sequencer,* or *rhythm box* is used.

In *direct* keyboards, the notes go through the keyboard's contacts. This is a traditional (translate "obsolete") route that can lead to crosstalk problems and may require many contacts for elaborate systems. It also greatly restricts the permissible envelope of the notes produces. The *indirect* keyboard, on the other hand, employs an electronic *keyer* or *voltage-controlled amplifier* (vca) controlled by the keyboard which, in turn, shapes and turns on and off the pitch envelope. The keyboard or controller works only with dc voltages that do not interact with each other and are readily combined, expanded, and controlled. Mechanically simple single-contact keys can be used in the keyboard, and things can be electronically expanded to whatever degree of control is desired.

Special Effects. Special effects introduced into the keyboard have to do with making the keys sensitive to pressure or velocity so that loudness can be controlled as well as the duration. In single-voiced systems, a memory must be provided after the key is released. In analog systems, a *sample-and-hold,* or *boxcar,* circuit is used, while in digital systems a latch-type memory is used.

Once the key is released, the decay portion of the note usually continues. The circuit must "remember" what note it is generating during the entire decay time; otherwise, the note would stop abruptly.

Coupling systems form another special effect, permitting one key to perform several functions simultaneously. Traditional organ couplers were used to add extra ranks of pipes to the voicing. The electronic equivalent allows the use of voicing associated with one keyboard or another or permits the addition of one octave higher or lower voices. In synthesizers, coupling can be added to gain chords, for scale translation, and to provide mutiple voicing.

The keyer, or vca, turns the notes on and off in a precisely controlled manner. It is very important that the keyer change only the loudness of the waveshape and not distort it as a function of the desired output loudness. So, the keyer must always be-have as a bipolar, electronically variable linear resistor—or as at least a two-quadrant multiplier. Keyers must be transparent to the tonal effects run through them.

If a note were simply turned on and off, it would sound phony and have some objectionable contact noise on the leading edge. The note that is allowed to build up rapidly (but not suddenly) and die down rapidly (but not instantaneously), as in Fig. 2A, would be about the very least acceptable. The rise time of the note is called the *attack*; its dwell time across the top is the *sustain;* and the drop-off at the end is the *decay*. Each of these times can be varied to obtain any desired sounds, ranging from a faithful immitation of a traditional instrument to "science-fiction" scores.

In Fig. 2B, the attack is rapid but not instantaneous. The sustain time is zero, and the decay time is very long. This is a form of percussion that is greatly enhanced if the keyboard initiates the action but does not determine how long it lasts. A refinement is added in Fig. 2C to gain realism. When a bell is first struck, its sound is very loud, rapidly dropping off to a much lower level. Finally, there is the same long decay of the percussion sound. All that has been done is to reshape the initial fallback, giving it a very fast decay time. If the bell were repeatedly struck, each individual strike would be distinctly heard, while repeated strikes with an envelope like that in Fig. 2B would be indistinct.

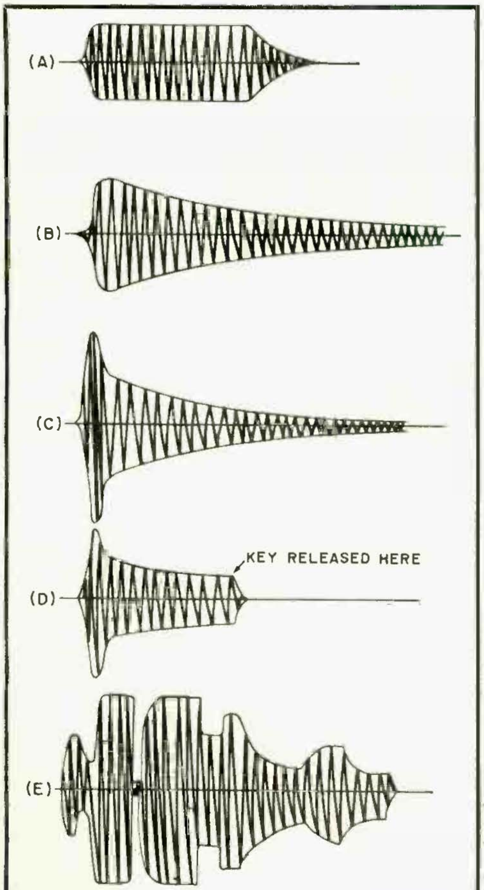


Fig. 2. These are some typical envelopes produced by various keyers.

A piano-type action where the decay continues gradually until the key is released, then suddenly drops to zero, is shown in Fig. 2D. This is called *snubbing*, and the final time interval is called the snubbing or damping time.

The envelopes shown in Fig. 2A through Fig. 2D are easily accomplished by adding diodes, capacitors, and resistors between the keyer and the keyboard. More parts are needed for the more complex envelopes. In Fig. 2E is shown the envelope obtained with an "unlimited" controller. The latter permits the generation of any waveshapes at all multiple attacks, sustains, echoes, etc. This can be done with computer control or with various special programmable envelope generators. Both techniques are very complex and costly when used with polyphonic instruments.

At this point, the keyed tones have the correct frequency and envelope shape, but they are still in the form in which they were generated—square, sine, or sawtooth waves. To obtain the desired sound, the waveshape itself must be altered. This is accomplished with voicing, or timbre, circuitry.

Voicing. The quality of a note is determined by both its fundamental frequency and its harmonic content. For instance, a flute tone is predominantly fundamental with a little bit of second harmonic; a string tone is an ordered series of harmonics similar to a sawtooth; and a horn is essentially the same thing run through a resonant acoustical circuit so that certain harmonics are emphasized.

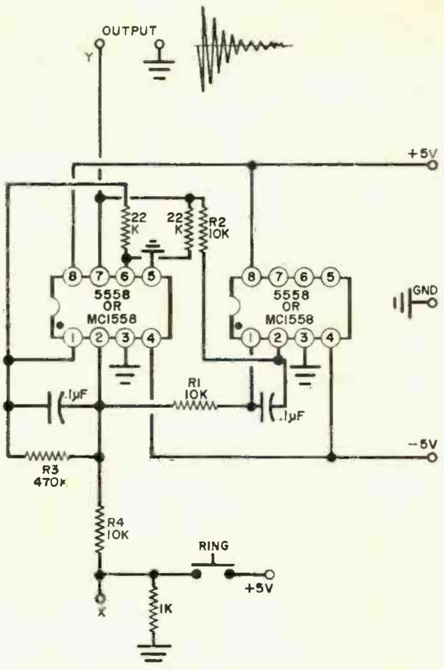
In general, voicing circuits can provide all notes with an identical harmonic structure, leading to an electronic or synthesizer sound. The harmonic structure can also be varied with frequency to yield a tonal structure more like most conventional musical

AN ELECTRONIC BELL

Traditional twin-T and bridged-T bell circuits suffer from stability problems and are difficult to design. Here we show a better way of doing things. Push the RING button and the bell sounds.

Coarse frequency is controlled by the capacitors which must be kept nearly identical to each other in value for best results. Fine tuning is accomplished with *R1* and *R2*. The decay time is controlled by *R3*.

This same circuit is useful as a high-Q filter. Send the signal in at point X and take it out at point Y. The response is bandpass, and the Q is controlled by *R3*. Gain is controlled by *R4*. Unlike practically all other active filters, none of the parameters in this circuit interact. The Q, frequency, and gain are pretty much independent of each other and are simple factors in the design.



instruments. The phase of the harmonic is not too important, but its amplitude is. There are four general ways of building up the desired harmonic content—or timbre—of the tone:

In the *additive* method, fundamental frequency sine waves and the desired harmonics are added together in the proper proportions.

In the *subtractive* (formant) method, one starts with a waveshape that contains all of the harmonics. Then the harmonics are selectively removed, attenuated, or emphasized to obtain the desired effect. A linear sawtooth is an excellent choice because all the harmonics are present. The sawtooth can also be converted linearly back to a square wave by subtracting one-half of a sawtooth of double the frequency from it.

In the *nonlinear* method, diodes or other nonlinear devices are used to generate new harmonics for suitable alteration. This method is limited to monophonic systems because intolerable distortion would result in polyphonic systems.

In the *replication* method, something akin to a "picture" of the desired waveshape is used, set up on a mask via slide potentiometers or in a computer memory.

In many synthesizers, *voltage-controlled* (active) *filters* (vcf's) are used to emphasize or attenuate harmonics selectively. This is a variation of the formant or subtractive method.

Special effects added after voicing can include echo and reverberation, frequency translation, etc. Frequency translation is done with sideband techniques and electronic multiplication. Control of gain and high-level amplification completes the electronic musical instrument.

More exotic sounds require more complex systems. For example, the voicing can be allowed to change throughout the envelope's time, perhaps letting the higher harmonics decay faster than the lower ones. Again, vcf is usually needed. Multiple voicing can be used for choral or unison effects. Two or three independent, but almost identical, voices are essential for piano-like sounds. Other complications can be introduced by making the overtone structure of the voice nonharmonic, as is the case with some stiff piano strings. Voicing can also be amplitude-dependent. Buzzes and sympathetic resonances can also be added.

Sometimes the voicing and envelope shaping are interchanged; other times they are part of the same circuit. The essential thing is to get the *product* of the desired envelope and timbre in an undistorted manner. ◆