Examines noise generators, instrument dynamics, and voltage control.

THE ELECTRONIC music synthesizer has changed the face of recorded music and live rock-band performances. This "instrument" can produce a myriad of unconventional, sometimes weird or eerie sounds. Yet it can also emulate the sounds of any conventional instrument.

There are two basic types of synthesizers: studio and performance. Modern studio synthesizers are made up of modular sections that consist of voltage-controlled amplifiers, filters, oscillators and noise generators, modulators and other devices. These modules can be interconnected in virtually any order by plugging their inputs and outputs together with "patch" cords. The output of almost any given module can be used either as part of the tone you eventually hear, or as the control voltage for another module. It all depends on how one "patches" the elements together.

Synthesizers designed for live performances do not use patch cords, as the time lost in changing patches during a performance would ruin the musical continuity. Here, the various modules are hard-wired together and the sounds are changed by a host of conveniently located switches and potentiometers, used much as stops are on an organ. Since a player can handle only a limited number of controls efficiently, performance synthesizers can't be made as flexible as the studio type.

How It Works. A synthesizer's output waveforms and control signals can be considered as a vast kit of parts from which musicians can assemble any desired sounds. The different parameters of each note—pitch, overtone structure, attack time, duration, and decay—are, in conventional instruments, fixed within narrow limits. In the synthesizer these parameters are independently, and almost infinitely, variable.

The modules that control those parameters are shown in Fig. 1. Pitch and overtones are controlled by the voltage-controlled oscillator (vco) and by the voltage-controlled filter (vcf). The note's attack, sustain, decay and release—its "envelope" in time—are controlled by the voltage-controlled amplifier (vca), which in turn is controlled by the envelope generator. The latter is sometimes called ADSR, the initials of the four parameters it governs—attack, delay, sustain and release. The musician's control input for these modules is usually a keyboard.

Normally, pitch is governed by the voltage-controlled oscillator. As the name implies, its frequency varies with the control voltage fed to it. But the vco also has an effect on overtone structure, or timbre. Its output can, on most synthesizers, be a pure sine wave, with no overtones at all, or a ramp, triangle, pulse, or square wave (see illustrations in Fig. 2), each of which has a different mixture of overtones.

Conventional instruments have somewhat similar overtone structures. A violin note, for instance, begins as a ramp waveform, the bow grabbing the string and deflecting it until the string's tension overcomes the friction of the bow, and the string snaps back again. A saxophone reed's opening and closing makes the equivalent of a square wave.

Don't think that these waveforms fully represent the sound of the instrument. They don't. The actual sound produced depends on the instrument's resonances, which accentuate or attenuate

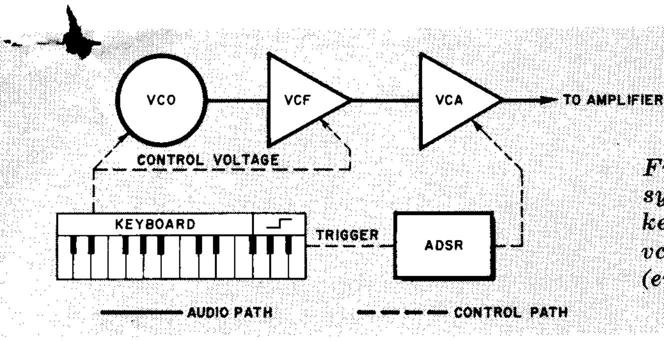

Fig. 1. "Classic" synthesizer consists of keyboard controller, vco, vcf, vca, ADSR (envelope generator).

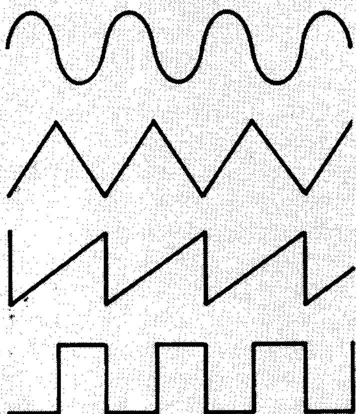

Fig. 2. Typical vco waveforms.

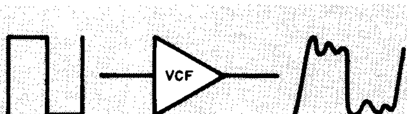

Fig. 3. Filter modifies timbre.

individual harmonic components in the raw waveform. The sound of a saxophone may begin as a square wave, but after passing through the instrument, it appears rather like the "ringing" waveform shown in Fig. 3.

The synthesizer's voltage-controlled filter has a similar effect to that of the saxophone's bell or the violin's hollow body. Whereas the resonators of mechanical instruments are reasonably fixed, a synthesizer's equivalent module (its vcf) can be used as either a low-pass, band-pass or high-pass filter over a frequency range of many octaves, while its "Q" (curve sharpness) is adjustable, too.The vcf can also give pitch to the output of an unpitched signal source, the 'noise generator.' At first it may seem odd to include such a module in a synthesizer, since so much attention is paid to eliminating noise in electronic systems. There are many applications, though, as illustrated in the next section.

The Noise Generator. The noise generator is used in simulating such instruments as the snare drum and the high-hat cymbal, or such natural sounds as wind, surf, explosions and thunderclaps. Using the synthesizer's other resources, it's also possible to create sounds that a real drum or real surf could never make. Let's try, for example, to invent a new musical instrument, with a voice like the wind. With enough experimentation, I'm sure that would sound much like the wind—perhaps a pipe with a plugger of some kind in it. With enough practice, we might even learn how to play it so that we were on pitch (and so that it didn't break into oscillation, which would ruin the effect). But it would take some work.

With a synthesizer, this type of task is almost ridiculously simple. First, we substitute a noise generator for the vco (Fig. 4). Then we recover pitch information from the noise (which contains all possible pitches) by passing it through the filter. To play this new instrument, we apply the keyboard's output voltage to the vcf's control input. Now, each keystroke will shift the filter's frequency range, controlling the pitch of the note.

Since the wind usually builds and dies away slowly, we'll want our instrument to have a slow attack and decay, and to sustain as long as we hold down the key. This is where the attack, delay sustain and release, or envelope generator, comes in.

Instrument Dynamics. Every instrument's note varies in amplitude over time. This variation—the instrument's "dynamics"—is one of our chief clues to which instrument we're hearing. (Note how odd most instruments sound when recordings of them are played backwards, even though pitch and overtones are the same.) In some instruments, the sound of each note builds up (attacks) quickly, and dies away (decays) slowly. In others, the attack may be slow, and the decay rapid. Some instruments' outputs begin to die away as soon as a peak is reached; others "sustain" for a time before decay begins.

Though it may not be immediately apparent, all of these characteristics are functions of the way energy is added to each instrument's mechanical system. In instruments where the energy is added all at once (whether by hitting it with a stick or strumming it with a plectrum), the note's volume will be at a peak immediately after striking; and since all of the energy goes in at once, there will be

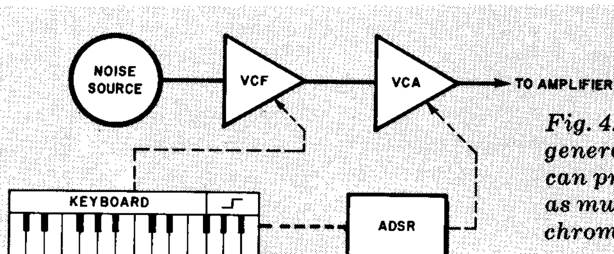

Fig. 4. "Tuning" noise generator output with vcf can produce such affects as musical wind and chromatic high-hat cymbals.

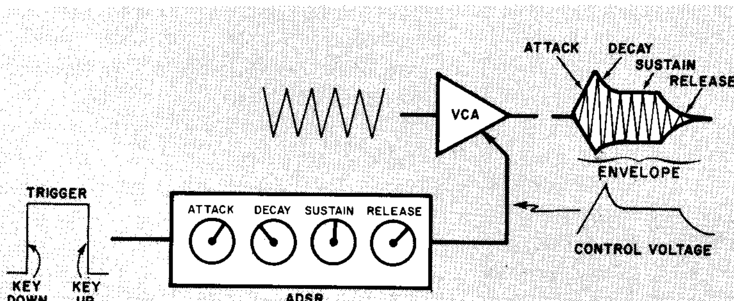

Fig. 5. The combination of a vca and ADSR.

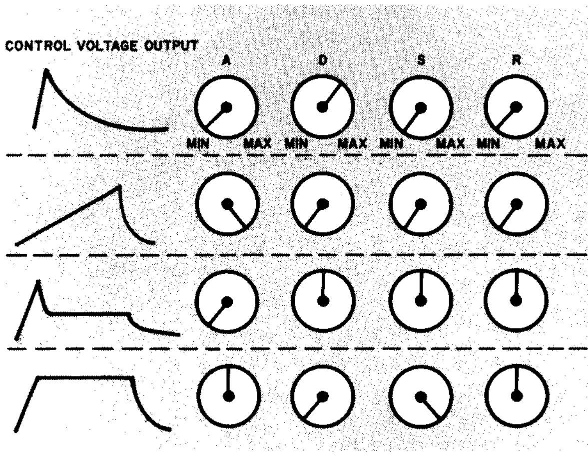

Fig. 6. By varying its ATTACK, DECAY, SUSTAIN *and* RELEASE, *envelope generator can produce different output waveforms.*

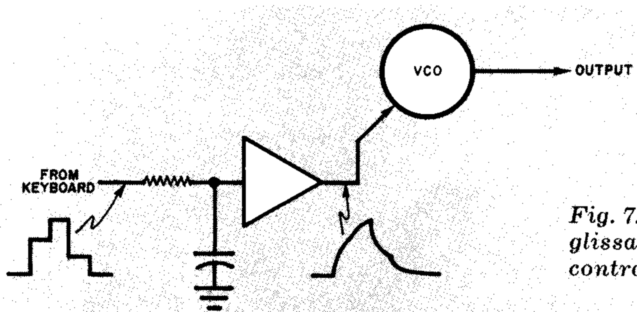

Fig. 7. An integrator adds glissando to a voltage controlled oscillator (vco).

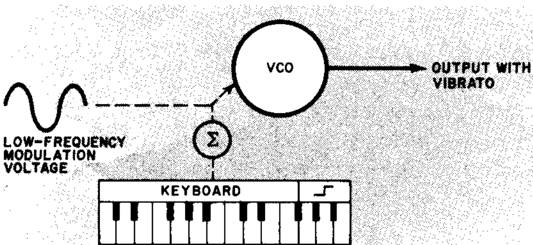

Fig. 8. Summation of control voltages results in special effects like vibrato.

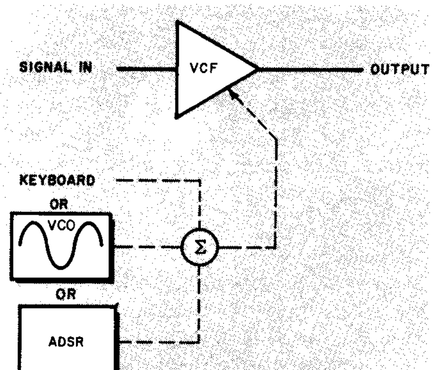

Fig. 9. Varying control voltages from vco or ADSR produce unusual effects.

none left over to sustain the sound—it's downhill all the way until the next note is played. This quick attack and moderate-to-slow decay is typical of instruments in the percussion family: guitar, piano, drums, xylophone, the heads of contestants on the "Gong Show," and such.

It would be natural to assume that we similarly "strike" the oscillator somehow to simulate this type of sound. But natural as this may seem, that's not how it's done. There's an easier way.

In a synthesizer, the oscillator runs all the time. Whether we hear it or not depends on whether the voltage-controlled amplifier (the last element in our "classic" patch) is on or off. And we control the dynamic shape of the note we're building by controlling the rate at which that vca turns on or off.

What controls the vca is the envelope generator or ADSR (Fig. 5). When it receives a trigger signal (usually from the keyboard), the ADSR's control voltage rises to a peak at a rate determined by the setting of the ATTACK control.

After reaching this peak, the control voltage begins to decrease at a rate set by the DECAY control. It doesn't fall all the way back to ZERO, though, just to a level set by a third control, SUSTAIN, where it holds for as long as the original triggering signal is present. Only when the trigger signal goes away (usually when the key on the keyboard is released) does the control voltage fall from the sustaining voltage to zero, and then at a rate set by the RELEASE control.

By adjusting these four controls—ATTACK, SUSTAIN, DECAY and RELEASE—we can cause the ADSR to generate a control voltage which, when used to determine how much signal passes through the vca, simulates the dynamics of any natural instrument (Fig. 6). It can also produce dynamics that would be difficult to produce with a mechanical instrument. An example would be combining the percussive attack of a drum with the sustaining properties of an oboe.

A synthesizer's oscillators and filters operate over an impressively wider frequency range than their mechanical counterparts, and have more modes of operation. A single electronic unit can even simulate a number of properties that might be mutually inconsistent in a mechanical device. But that's only part of the story.

Voltage Control. The real story is voltage control. A synthesizer's oscillator and filter frequencies and amplifier gain are all functions of the control voltages applied. That's more significant than it may look at first.

The keyboards used with most synthesizers are nothing but switch-selectable voltage dividers. Press a key, and a voltage that represents that key appears at the keyboard's output. Press another key and the voltage instantaneously changes to a new level. If the voltage from the keyboard is being used to set the pitch of the oscillator, the output instantly steps from the first note to the second. There will be times, though, when it will be desirable to produce a sound that doesn't instantly change from one pitch to another, but rather glides (glissandos) between notes. Because of voltage control, a simple integrator (nothing more than a register, capacitor and buffer amplifier) placed in the keyboard-to-oscillator control voltage path will produce this effect by slowing down the change (Fig. 7).

Other special effects can be added easily by summing control voltages from several sources. Vibrato, for example, which is a slow-speed modulation, is realized by summing a slowly varying (7–12 Hz) control voltage into one of the control voltage inputs of the vco (Fig. 8). Applying this same modulating voltage to the vca produces tremolo, a slow variation in the output amplitude.

Since the center or corner frequencies of the filters used are also functions of summed control voltages, several vastly different acoustical instruments can be simulated simply by changing the source of the control voltages that we apply to this element.

If the voltage comes from a fixed source, the output would simulate an instrument with a fixed resonator such as a guitar or piano. However, changing the control voltage allows one to instantly change the properties of the resonator (try *that* with a piano). Moreover, if the control voltage comes from the same source that is supplying pitch information to the oscillators, we can simulate the properties of instruments with variable resonators, such as reed and wind instruments (Fig. 9).

Filter control voltages that vary with time can vary independently of the voltage that controls the oscillator, allowing the filter to sweep the harmonic content of the oscillator's output cyclically (a cross between tremolo and vibrato that is rare among natural instruments). Or, the control voltage can be derived from an ADSR, for a "waa-waa" effect.

Getting back to our "wind" instrument, the desired sighing quality can be easily attained by simply adjusting the envelope generator for a slow attack and decay, a high sustain level, and a slow release. Tiring of that, one need only change the settings of the ADSR to fast attack, no sustain, and moderate decay, to set up an entirely new "instrument." This one will sound like a "chromatic high hat cymbal," one that is played from a keyboard. This would not be only for rhythm, but also as a lead voice in a composition. (Try *that* with your pipe and plugger!) The pitch and range of the filter can be changed, too. Bring an oscillator in, and begin simulating snare drums that can be played in pitch. There's no end to the possible variations achievable with patch-cord type synthesizers.

If you have access to a synthesizer, you'll have instrumental and other sound available for recording right at your fingertips. And if you think that you don't like synthesizer sounds, perhaps you should begin listening more carefully to modern pop, jazz and rock recordings. The next time you hear what appears to be a chorus of violins, read the album's liner notes—they might not be real violins at all! ◇