P. Moog Synthesizer I

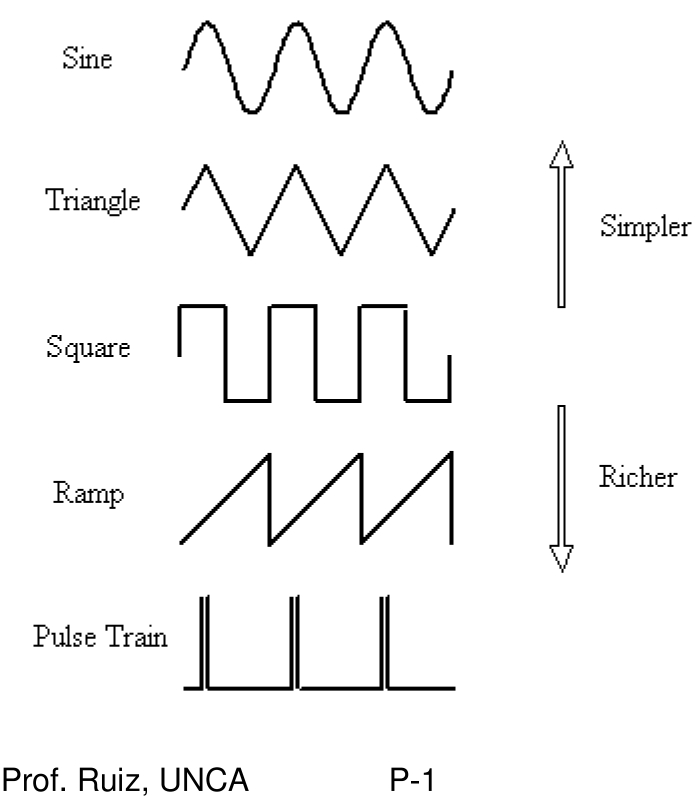
The music synthesizer was invented in the early 1960s by Robert Moog. Moog came to live in Leicester, near Asheville, in 1978 (the same year the author started teaching at UNCA). Although, there were examples of electronic music before 1960, the key discovery of Moog was *voltage control*. Moog used voltage to control sound characteristics. Consider loudness. You can turn a volume control up with your hand. This may take a half of a second. However, if the volume is turned up electronically, it can be up in a thousandth of a second. The result is a plucking sound. The use of electronic modules dedicated to different tasks along with voltage control brought about the music-synthesizer revolution of the recent generation.

We take a modular approach in covering the synthesizer. Each section introduces a new module. In this text, symbols are taken from standard electrical engineering convention. As each new module is introduced, we combine it with the other modules covered before it. In this way, the architecture of the synthesizer unfolds before us in an elegant and satisfying manner. Discussion focuses on the early basic modular synthesizer, where you have to patch all the connections yourself. This provides us with an excellent foundation.

Voltage-Controlled Oscillator (VCO)

An oscillator produces a basic waveform that can later be modified by other modules. Five fundamental waveforms produced by electronic circuits are given in Fig. P-1. We have encountered them before. These waveforms range from simple sounds to rich ones.

Fig. P-1. Five Basic Oscillator Waveforms.



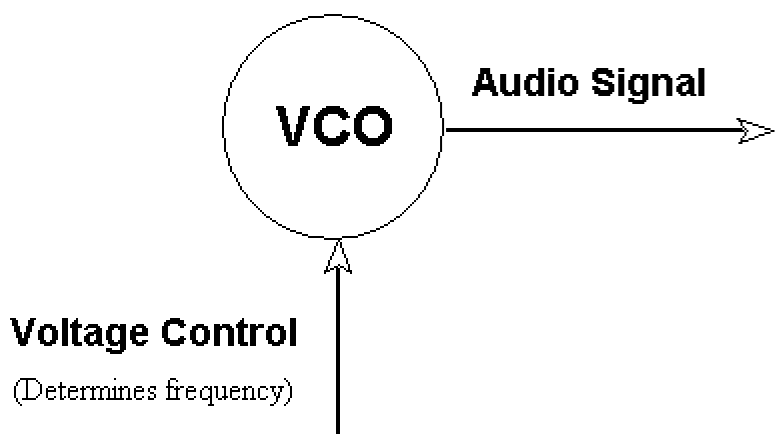
The circuit symbol for an oscillator is a circle. We use the circle in this text to represent the VCO (see Fig. P-2). Another convention in this text is to let audio signals travel from left to right and control signals enter the modules they control from below the module. In Fig. P-2, the voltage entering from below determines the frequency of the audio signal. The voltage controls the oscillator (VCO). For example, the control voltage usually ranges from 0 to 10 volts. Low-frequency audio signals with frequencies like 60 Hz may require 1 volt, while a 16 kHz-tone may need 9 volts.

The audio signal must be sent to a standard amplifier/speaker unit to be heard. This last step is omitted in our synthesizer diagrams. It is assumed that this final connection is provided. Note the simplicity in function of the VCO. Its task is very specialized and simple.

You can assume that the choice of different waveforms are made by a switch. In the early modules you actually insert a wire, called a patch, into the desired jack on the VCO. If you are communicating by a synthesizer "formula" for a friend to reproduce your sound, you can include the waveform instructions on the diagram. You may simply sketch the waveform inside the circle. You can do this underneath the letters "VCO" or sketch it in place of the letters. The circle indicates oscillator and the waveform inscription inside the circle reinforces the idea that the circle is an oscillator.

The modular diagram can serve as a way to communicate to others interesting sounds you have synthesized. The complete diagram or recipe is also called a *patch*. Today, with so many preset patches, we do not have much need for recipes. A modern synthesizer often has over 100 preset sounds called *voices*, more than enough for the average user. Many users do not want to "discover" or "invent" their own sounds, but rather prefer to use those offered by the manufacturer. Different makes of synthesizers vary in how much the user can do in the way of making new voices.

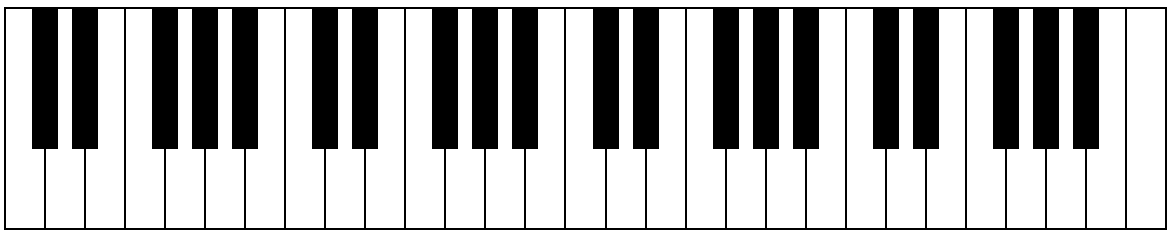
Fig. P-2. The Symbol for the VCO.



Keyboard (KBD)

The keyboard (see Fig. P-3) is the device that usually controls the oscillator. However, it can be a guitar or other instrument. Due to the popularity of the keyboard, many musicians who play other instruments have some knowledge of the keyboard. The piano has always been a fundamental instrument for musicians as it gives an easy visual representation of harmony, it offers accompaniment capability for singers, and it is readily available.

Fig. P-3. Keyboard.



The symbol for the keyboard is given in Fig. P-4. We abbreviate the names for all modules, usually with three letters. A rectangle is the symbol we choose for a control module. When a key is pressed, two things happen. First, the control voltage assumes a voltage value depending on which key is pressed. This voltage enables the VCO to sound the right pitch. The control voltage continues after the key is released. This feature is called *sample and hold*. Remember that the task assigned for each module is kept as simple as possible.

Second, the trigger voltage is activated when a key is pressed. It is deactivated when the key is released. We will see later how to use this. Think of it as a binary on-off or "yes-no" voltage ("yes" if any key is held down, "no" if all keys are up).

Fig. P-4. The Symbol for the Keyboard (KBD).

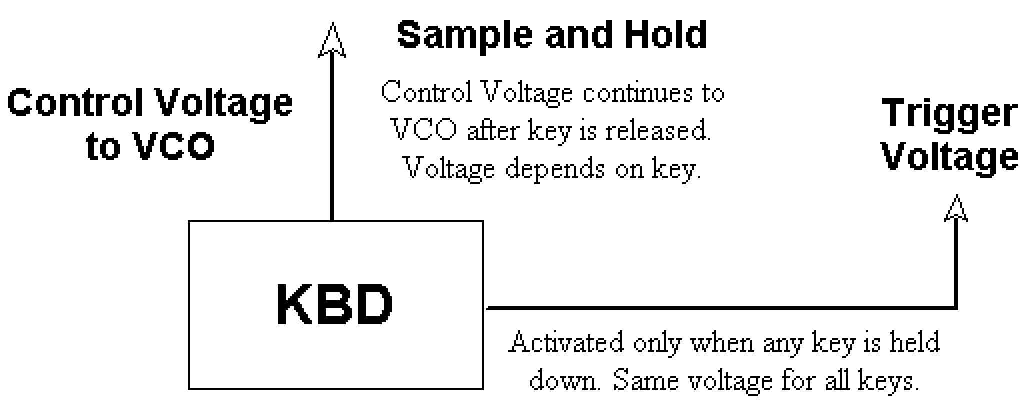


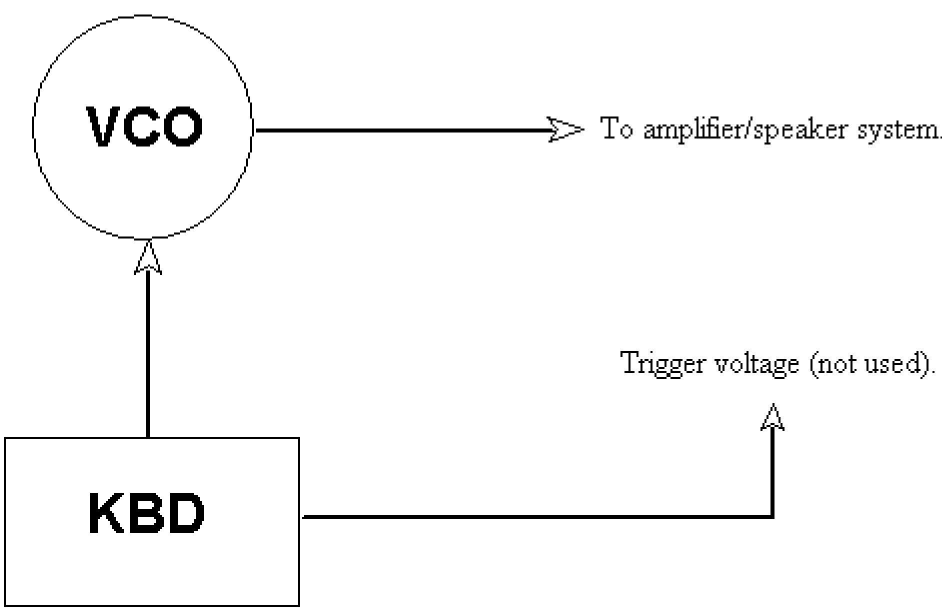
Fig. P-5 illustrates the keyboard (KBD) working together with the voltage-controlled oscillator (VCO). The keyboard control voltage tells the oscillator which frequency it should oscillate at. The waveform is chosen manually by you. You flip a switch at the VCO or plug the audio cable into the desired opening on the VCO for the waveform of your choice. The trigger voltage is not used in Fig. P-5. The arrangement in Fig. P-5 produces a tone when a note on the keyboard is pressed. When the key is released, the tone is still made by the VCO due to the sample-and-hold feature.

Note that you can only use one note at a time. You can't play two notes at once. The reason is simple. There is only one oscillator, i.e., one VCO. Additional oscillators are needed if you want to play more than one note simultaneously. We will stick with one VCO in our diagrams so that we can master all the fundamental features of the modular synthesizer.

Playing more than one note simultaneously is called *polyphony*. A polyphonic synthesizer has several oscillators in order to do this. The common synthesizer today offers at least 8-note polyphony. This is usually enough for a performer. With two hands you can hit 10 notes at one time and exceed this number by letting the thumb handle 2 notes. But this is not typical. For synthesizers with computer capability (MIDI), the voices are independent and the computer can play different instrument voices at the same time.

Composers may need more independent voices such as 16. Many MIDI synthesizers are 28-note polyphonic. The popular Roland XP-50 workstation has 64-voice polyphony. However, some sounds require the synthesizer to use more than one of its voices to produce it. For all practical purposes, this reduces the actual note polyphony. You need to consult the manual to see how many voices are needed to produce a sound of your choice. This can amount to a significant reduction on some synthesizers. Check the manual and listen to the sounds before purchasing an expensive unit.

Fig. P-5. KBD Controlling VCO.



Voltage-Controlled Amplifier (VCA)

The voltage-controlled amplifier is an amplifier that is controlled by voltage. Instead of turning it on with your hands, you can connect a 1.5-volt battery to it. More voltage means more amplification. Two batteries in series (one on top of the other) supplies 3 volts and the sound is louder. But of course, we don't use batteries. There is another module (to be taken up in the next section) that is used to control the VCA. Remember that each module specializes in a small task.

Fig. P-6 illustrates our symbol for the VCA. We choose a triangle since the triangle is the standard symbol for an amplifier in electrical engineering. An audio signal is sent into the amplifier and a modified signal is sent out. The amplitude of the signal is modified by the input control voltage. Remember our convention that audio signals progress from left to right and control signals are drawn controlling from below. The control voltage has values in the range of 0 to 10 volts like the VCO. Control signals can be steady or changing. The audio signals leaving the VCO are always periodic waveforms with frequencies in the range of human hearing. The VCO electrical oscillations are therefore always alternating in current (AC).

The voltage amplitudes for the AC audio signals are low, in the millivolt (mV) range like typical sources. The VCA controls the amplitude to achieve many interesting electronic effects rather than boosting it in the usual fashion to drive a speaker. You still need the regular amplifier. Once again, we do not show the last two stages in sound systems: the amplifier (2nd stage) and the speaker stage (3rd stage). All of our synthesizer diagrams depict the source stage (1st stage). Other sources we have studied include the microphone, CD player, and radio. Your standard stereo amplifier (receiver) has auxiliary inputs to handle an additional source such as a synthesizer.

Fig. P-6. The Symbol for the VCA.

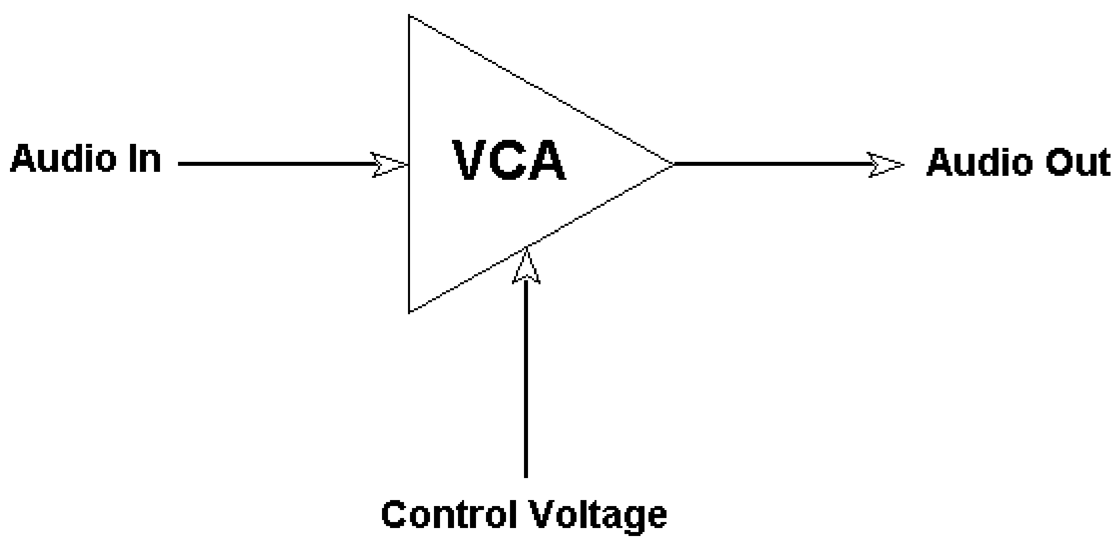
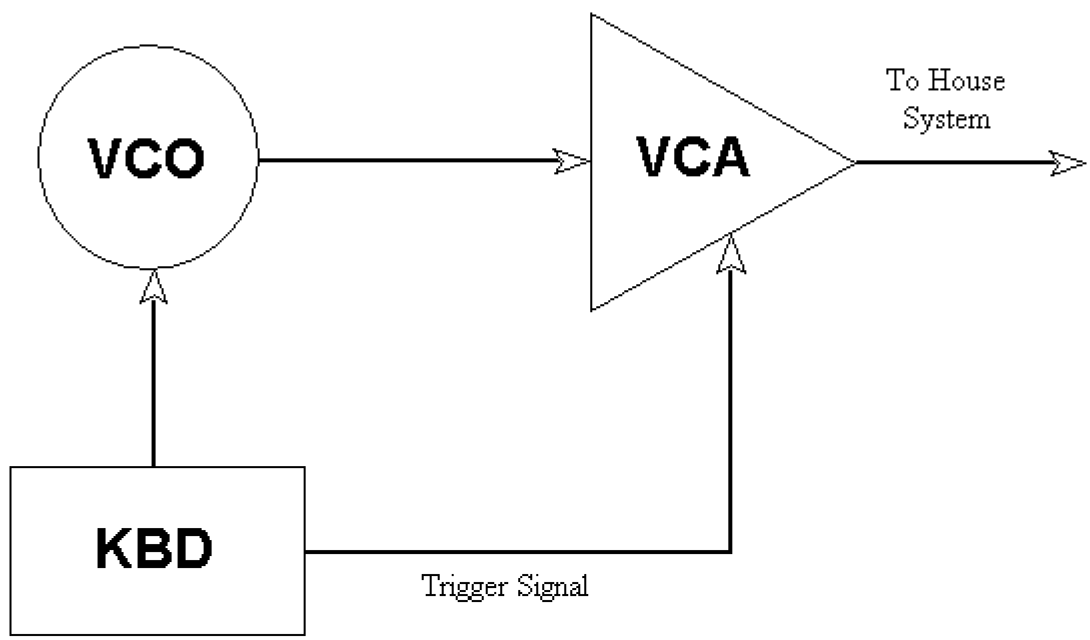


Fig. P-7 illustrates the simplest way to combine the VCO, KBD, and VCA. The keyboard controls the oscillator as before. However, now we take the trigger voltage and apply it to the amplifier. Remember that the trigger voltage is either on or off, depending on whether a key is held down or not. The signal is the same for all keys. Pressing any key results in the same "on-voltage" in the trigger line.

Pressing a key then does two things. The keyboard sends a control voltage to the VCO to tell it which frequency to oscillate at. This voltage depends on the key. A key to the left on the keyboard sends a low voltage to the oscillator and the oscillator produces a bass tone. Keys to the right on the keyboard send higher voltages, resulting in treble tones. The keyboard sends out a second control voltage, this one to the VCA. This voltage is the same for any key. When a key is pressed, the trigger voltage informs the VCA, which then amplifies the incoming signal. When the key is released, the amplifier cuts off the incoming signal.

When the amplifier cuts the incoming signal off from going to the output, the input signal is still there trying to get through. This is a result of the sample-and-hold feature of the keyboard. It is important because the VCA may want to do more things to the incoming wave. In our simple case it cannot. But if we have a more elaborate control voltage entering the VCA than the simple trigger voltage, we obtain more interesting sound effects. We take this up in the next section. For now, our control is a simple on-off. We hear an abrupt start when a key is pressed. The tone is steady when the key is held down. When released, the tone ceases just as abruptly as it started.

Fig. P-7. Simplest Arrangement for VCO, KBD, and VCA.



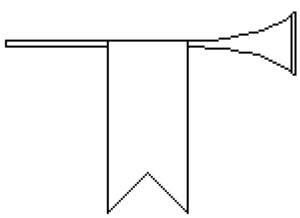
Envelope Generator (ADSR)

The control offered by the trigger voltage is not very satisfactory. The trigger voltage is not designed to feed directly into the VCA. Its purpose is to activate another module, the envelope generator, which in turn controls the VCA in a much more sophisticated manner. The trigger voltage turns the VCA on abruptly when a key is pressed (see previous section).

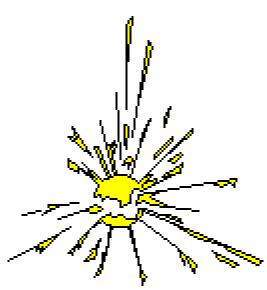
The turn-on phase of a sound is called the *attack* phase. When a key is released, the trigger turns the VCA off abruptly. This last phase of the sound is called the *release* phase. If the key is held down, there is an additional phase to the sound, the *sustain* phase. For quickly pressing and releasing a key, the trigger control on the VCA provides us with a simple analysis for the sound: an abrupt or short attack and an abrupt or short release phase. When you strike a bell, the attack phase is abrupt but the release phase of the sound is long.

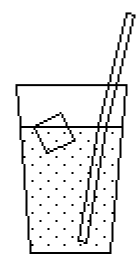
Table P-1 lists four sounds depending on whether the attack and release is either abrupt or gradual. There are four possible basic combinations. We are not considering a sustain phase at this time. The sound takes an amount of time (attack) to reach a maximum level, then immediately begins to die away (release).

Table P-1. The Attack and Release Phases of Sound.



Attack	Release	Sound
Abrupt	Abrupt	Staccato
Abrupt	Gradual	Explosive
Gradual	Abrupt	Sucking
Gradual	Gradual	Swishing





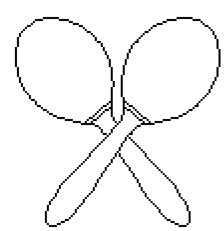


Fig. P-8 illustrates four phases for a sound. The sound begins during the attack phase. Then there is a *decay* to the sustain level. The sustain level continues until the key is released, at which time the release phase begins. This four-part method is very powerful in shaping a multitude of sounds. The wave being shaped in Fig. P-8 is a square wave. Fig. P-9 illustrates the four phases of the envelope or outline. The amplitude shaping here is a form of amplitude change or modulation, however, the change doesn't keep repeating. The square wave can be considered to be the carrier wave. The modulator wave shape is the envelope contour (Fig. P-9).

Fig. P-8. Shaping the Amplitude of a Square Wave.

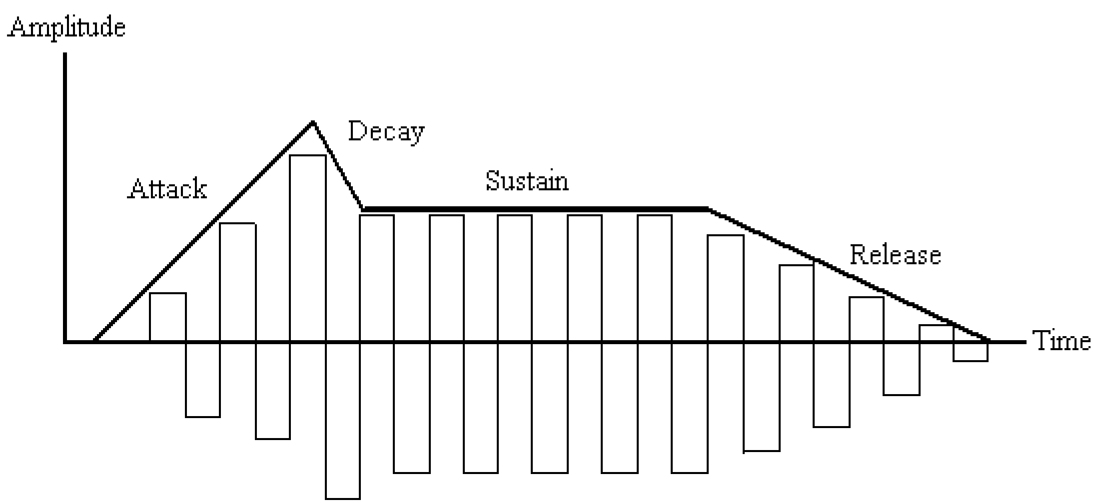


Fig. P-9. The Four Phases of the Envelope.

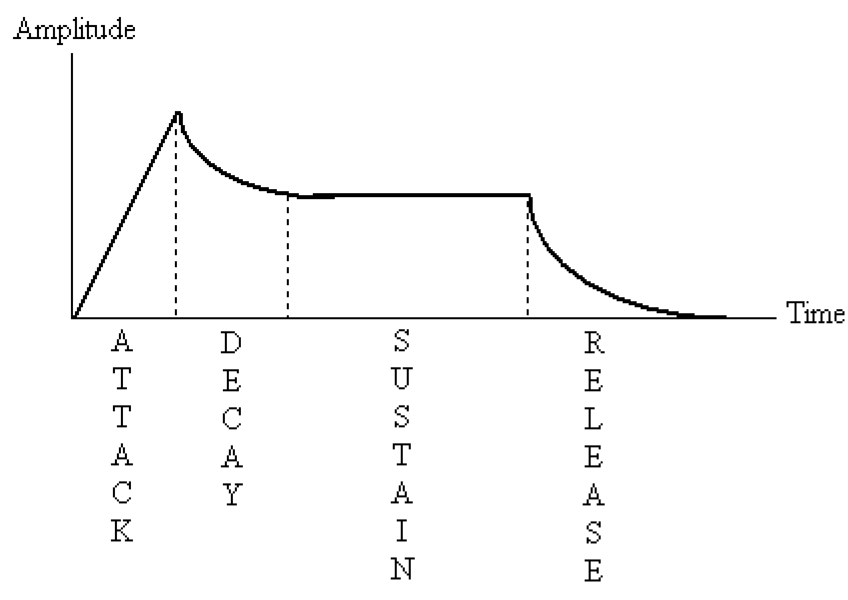


Fig. P-10 at the right gives the symbol for the envelope generator. It is a controller so a rectangle is used. The ADSR is controlled by the trigger, and the ADSR in turn controls the VCA. You press a key and the trigger "fires up." This tells the ADSR to go through a preset program. It immediately turns on the VCA for the duration that's set previously for the attack phase. Think of 4 knobs on the ADSR unit, one for each phase.

An attack setting of 1 ms gives a percussive start, while a setting of 1 s is a long beginning, like slowly playing a harmonica. The decay phase follows for the time set for it. This phase brings the sound level down to the preset sustain value. The ADSR continues sending out the sustain voltage for the sustain phase until you release the key. Upon release of the key, the trigger voltage goes off. The ADSR begins the release phase, turning the VCA off according to another preset value.

The settings (preset) for the attack, decay, and release are time values, usually between 1 ms and 1 s. The sustain setting is a voltage value. The time for this phase is determined by how long a key is held down. Fig. P-11 illustrates the VCO, KBD, VCA, and ADSR working together. A variety of musical sounds can now be synthesized by shaping the available waveforms.

Fig. P-10. Symbol for ADSR.

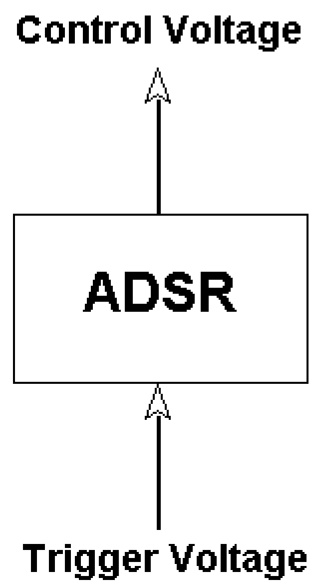
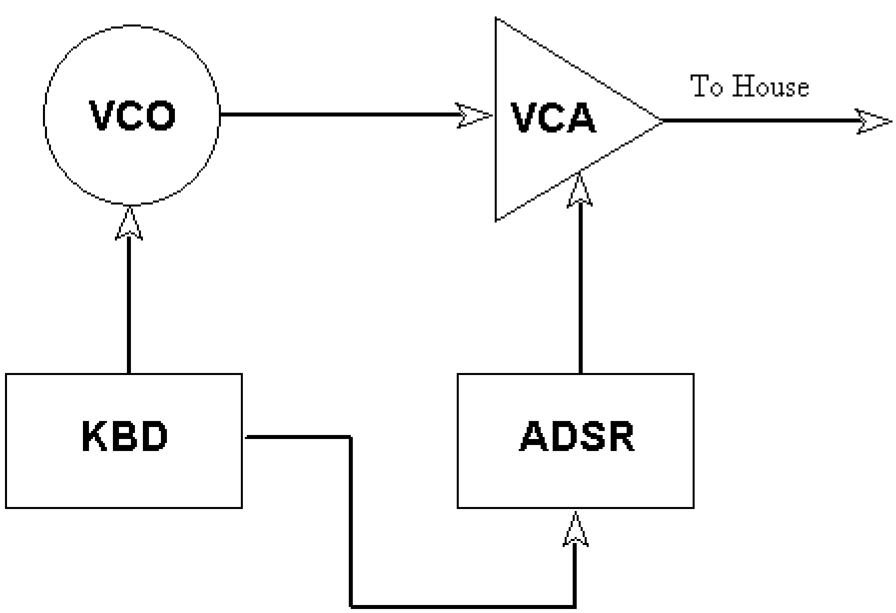


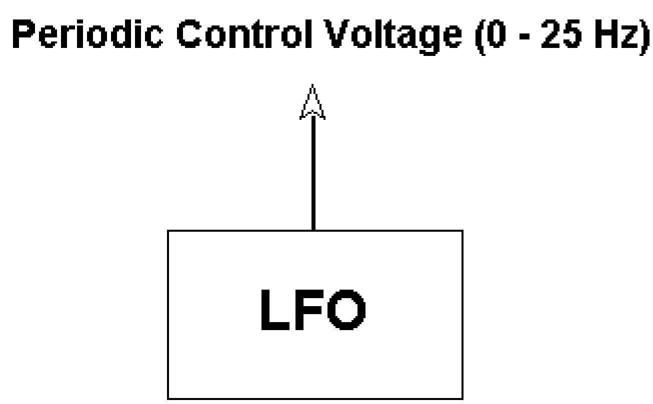
Fig. P-11. The VCO, KBD, VCA, and ADSR.



Low-Frequency Control Oscillator

The ADSR shapes the carrier waveform once for each key press. We mentioned that this change is, in a sense, a modulation. You might say that the ADSR performs an aperiodic modulation, while the more usual type of modulation is periodic modulation. We have discussed the three basic types of modulation: amplitude modulation, frequency modulation, and timbral modulation. These types of modulation can be achieved electronically. A special controller is dedicated to performing periodic changes on waveforms. This unit operates at the low frequencies, as we expect, for the usual modulation discussed in a previous chapter (0 - 25 Hz). See Fig. P-12.

Fig. P-12. Symbol for Low-Frequency Control Oscillator.



In Fig. P-13 below, the LFO is used to obtain the two familiar types of modulation, AM and FM. The LFO simply controls the appropriate module in each case. The LFO has settings for your modulating frequency and the sweep range. For example, you can sweep the VCO over small ranges for vibrato or large ones for siren effects.

Fig. P-13a. Tremolo.

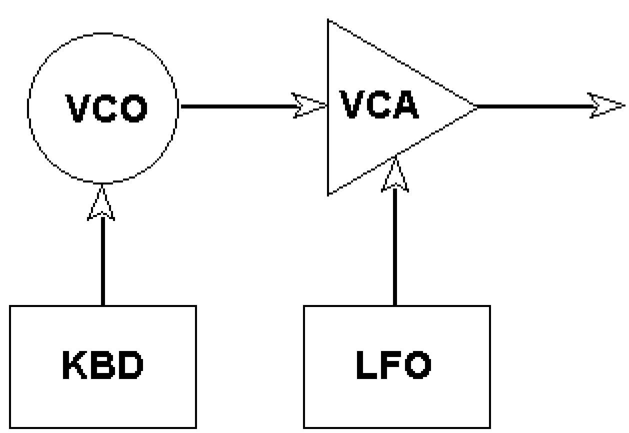
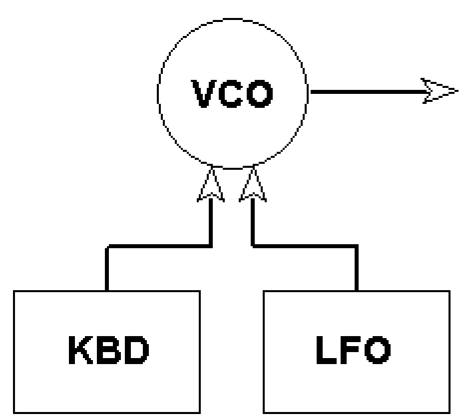


Fig. P-13b. Vibrato.



Note that two signals go into the VCO in our example for vibrato. The VCO can accommodate these signals. The voltages are added together. Then the sum controls the VCO. The control voltage from the keyboard sets the base frequency or tone. Perhaps this voltage is 3 V. The voltage from the LFO then provides an additional fluctuating voltage to it. For a vibrato, this extra periodic voltage may vary a little, e.g., fluctuating between 0 and 0.1 V. The tone raises its pitch a little and then lowers it back and so on. The rate at which this occurs is determined by the frequency setting on the LFO. For sweeping siren sounds, the LFO voltage may vary from 0 all the way up to 1 V and back down again periodically.

More practical arrangements for synthesizing a tremolo or vibrato are built from the basic arrangement of the VCO, KBD, VCA, and ADSR working together. Then the LFO is brought in to provide the appropriate modulation. These patches or arrangements are shown in Figs. P-14a and P-14b. The LFO generates its own frequency. Nothing ever is sent to the LFO. We use the rectangle for the LFO because it produces a control voltage rather than an audio signal like the VCO.

Fig. P-14a. Playing a Tune with Tremolo.

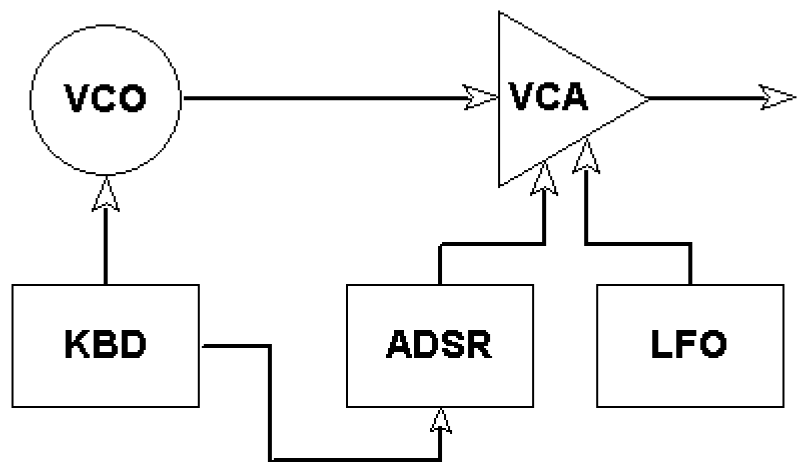
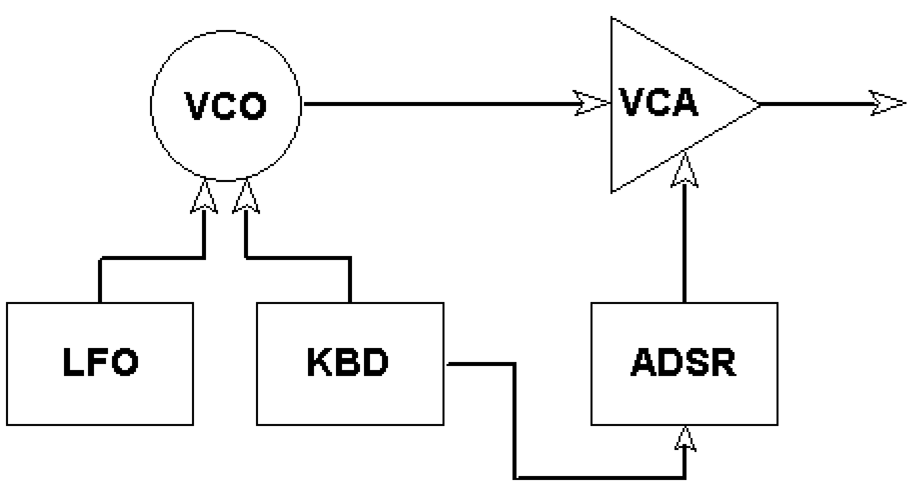
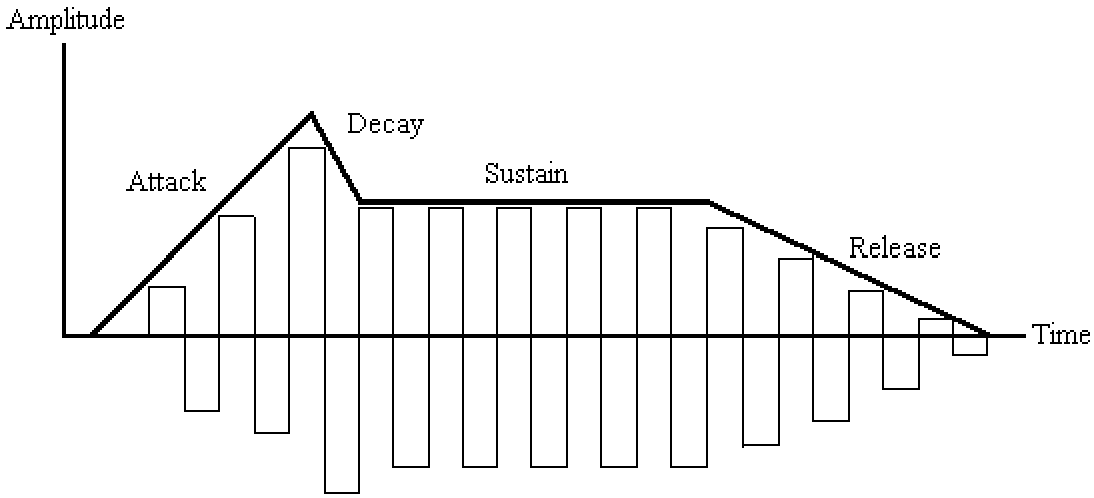


Fig. P-14b. Playing a Tune with Vibrato.



An Exercise



Description	T	F
There are four cycles of the square wave tucked inside the attack phase (see above).	○	○
The sustain phase always contains the greatest number of wavelengths.	○	○
A couple of milliseconds is an example of an abrupt attack time.	○	○
The sustain phase is longer than the release phase in the above diagram.	○	○
The release phase is longer than the decay phase in the above diagram.	○	○
For a real audio example, the above wavelength must be made extremely shorter.	○	○

--- End of Chapter P ---

