# Q. Moog Synthesizer II

In the previous chapter we introduced five synthesizer modules: the voltage-controlled oscillator (VCO), the keyboard (KBD), the voltage-controlled amplifier (VCA), the envelope generator (ADSR), and the low-frequency oscillator (LFO). In this chapter we introduce two more: the noise generator (N), and the voltage-controlled filter (VCF). These seven modules are the basic modules of the modular synthesizer.

**Noise Generator (N)**

The engineering definition of noise is a sound that has a mixture of all frequencies. When there is fairly equally-perceived distribution of all frequencies, we have *white noise*. This name comes from an analogy with light. Newton discovered that white light consists of all the colors in the visible spectrum. If you shine white light through a prism, the light breaks up into the spectrum of colors from violet to red. Violet has the shortest wavelength and highest frequency. The violet light is nearly twice the frequency of red light.

We see about an octave in color. All the colors within this octave mixed together appear white to our eyes. With sound, we hear many octaves. The piano alone has 7 octaves. We can hear a few additional octaves beyond the piano. The frequency range for hearing is often reported as 20 to 20,000 Hz. However, most people lose it somewhere between 10,000 Hz and 20,000 Hz. A fairly equal representation of sound from 100 Hz to 10,000 Hz is taken to be white noise.

An excellent example of white noise is the roar of the ocean. The turbulence of the water at the beach or shore is so varied that frequencies of sound across the audio spectrum are produced. Some claim that putting a seashell to your ear reproduces the ocean sound, having captured it mysteriously in some way. You do hear sound when you place a seashell to your ear, and it is white noise. The white noise is not due to the ocean though; it is noise resulting from random movement of air molecules due to temperature. You can get a similar effect by holding a glass to your ear or cupping your hands over an ear.

Steam is another good example of noise. You need to be careful if sounds of steam get loud because all frequencies are represented. This has the potential to damage your hearing. Technicians working near steam turbines in power plants wear ear protection. Another example of white noise is the noise a fan makes. The yells and cheers of a baseball or football game heard from afar approximate white noise. Far away you get a better mix of the sound. Can you imitate the distant sound of cheers by making sounds with your mouth?

We are more sensitive to higher pitches than low ones. The noise that sounds fairly uniform is actually somewhat lacking in lower frequencies. If we really have equal amounts (by the reading of a meter) for all frequencies, the noise sounds a little deeper. Engineers use the term *pink noise* for such noise since it appears to have a greater presence of low frequencies. Going back to the analogy with light, white light with a presence of more low-frequency red is pink.

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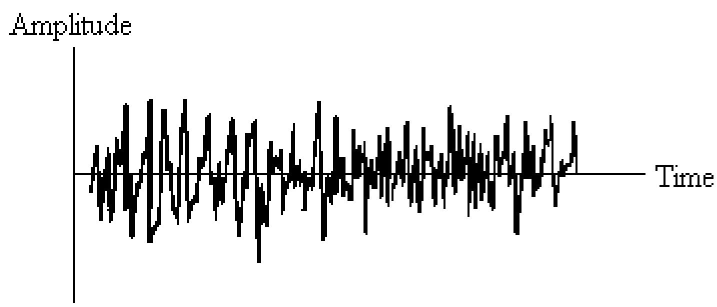
Noise is illustrated in Fig. Q-1. This figure represents a snapshot of noise as it appears on an oscilloscope. The mixture of so many wavelengths produces a chaotic pattern that constantly shifts on the oscilloscope. The many frequencies present in noise are evident by the many different wavelengths superimposed. The low frequencies have long wavelengths, while high frequencies have short wavelengths. The combined waveform is aperiodic. The wave patterns do not repeat. Therefore, there is no defined pitch as we find in periodic waves. Fig. Q-2 below illustrates some examples of noise.

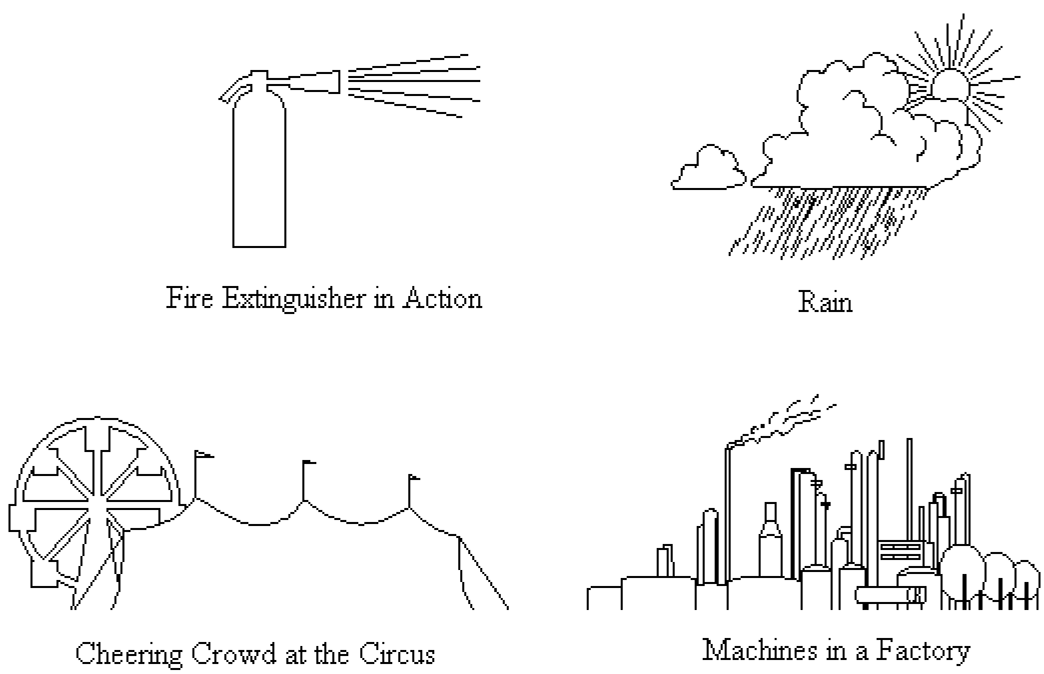
Fig. Q-1. Oscilloscope Showing Noise.

White Noise - all frequencies together.



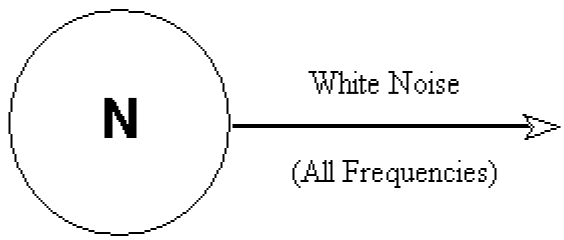

Note that the waveform is aperiodic.

Fig. Q-2. Some Examples of Noise.



Noise can be made electronically by forcing a current into a transistor the wrong way. This causes microscopic havoc. If you overdo it, you destroy the transistor. But in smaller amounts, electronic noise is produced. This is all we want for the noise source. Our noise generator does just this and nothing more. The symbol for the noise generator is given in Fig. Q-3 below.

Fig. Q-3. Symbol for Noise Generator.



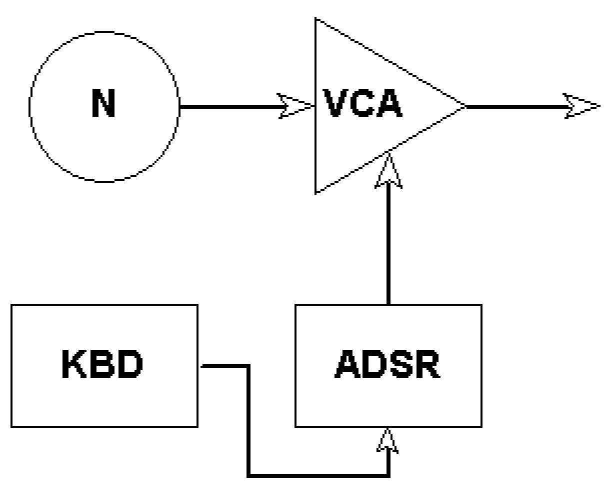

The circle is used for the noise generator because it is a module that generates audio signals. The VCO also generates audio signals. However, there are some differences. The noise generator has no input control signal. It always produces noise. The reason we need to control the VCO is that the VCO produces one frequency at a time. We need to tell the VCO which particular frequency to produce by playing a key of our choice on the keyboard. Since the noise source N produces all frequencies in a random mixture, the noise generator needs no instructions.

You might wonder why the noise source is always on. But we want this. Recall that the VCO always sends out whatever the last key instructs it to do. This is sample and hold. Likewise the noise source keeps sending out white noise. Each module is asked to do very little. We need all the modules working together to produce the final desired outcome.

See Fig. Q-4 for a simple example. It doesn't matter which key is pressed. The effect is the same. Each key produces the same trigger.

Quick attacks and gradual releases can synthesize explosions. Explosions have many random frequencies (noise). Gradual attacks and abrupt releases synthesize sucking on a straw (random turbulent motion of the liquid produces noise). It's best to just press and quickly release the key for these. If a key is held down, steady-state noise is maintained.

Fig. Q-4. Simple Use of Noise.

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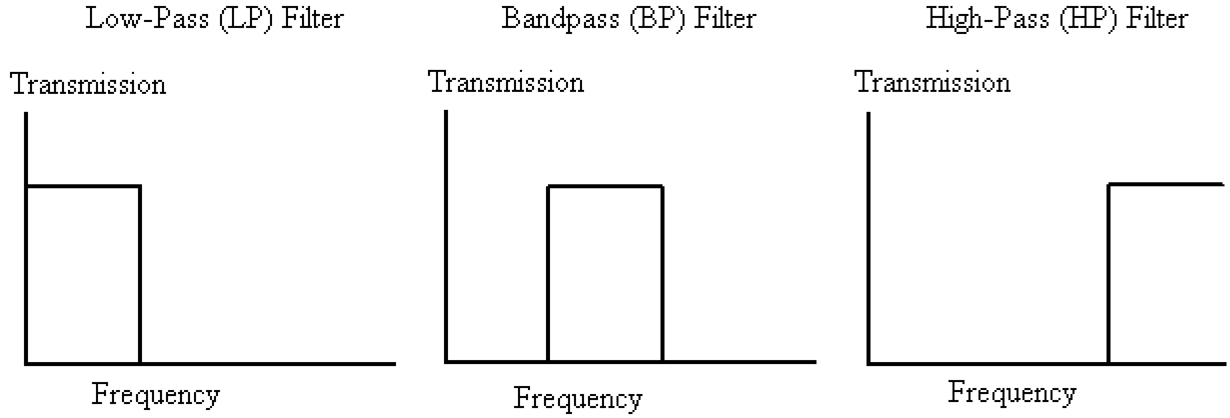
**Voltage-Controlled Filter (VCF)**

The last module of the basic seven units that comprise the modular synthesizer is the voltage-controlled filter. The filter allows us to modify the waveform, shape the timbre. The filter can alter the Fourier spectra of our basic periodic waveforms that originate in the VCO. The filter can also modify the sound from the noise generator. We can filter out high frequencies and approximate pink noise.

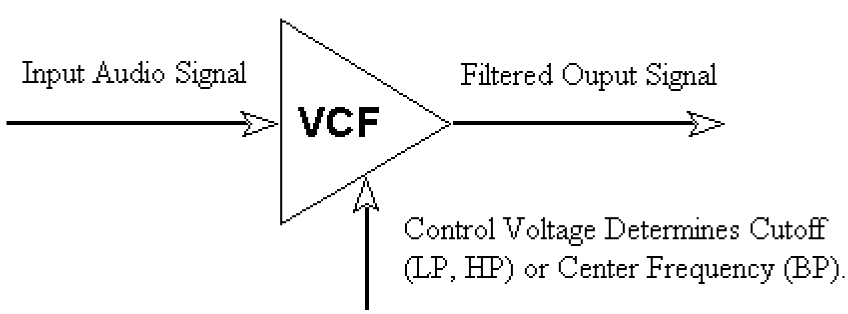
When we employ light with colored filters, we get different colors. The color we see is the color transmitted by the filter. A blue filter transmits blue light. We might say that white noise going through an electronic filter produces "colored noise." The three basic filter types are reviewed in Fig. Q-5 below.

Fig. Q-5. Review of the Three Basic Filter Types.




The filter graphs above give the transmission percentage for a sine wave at each frequency entering the filter. Periodic complex waves must be decomposed into their Fourier spectra in order to analyze which harmonics can pass through. The symbol for the VCF is given in Fig. Q-6.

Fig. Q-6. Symbol for Voltage-Controlled Filter.

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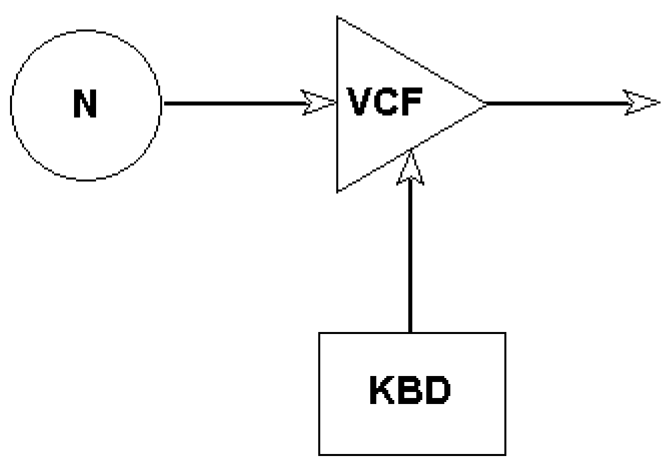
The symbol for the voltage-controlled filter (VCF) is a triangle. The triangle is the symbol used for the amplifier, which modifies the audio signal's amplitude overall. The filter works on individual spectral components. It modifies the amplitudes of the partials that make up a periodic waveform. It modifies noise, filtering out some sine-wave frequency components, passing others. Therefore, the triangle is the logical choice. Think of the triangle symbol as one that represents a device that accepts an audio signal and modifies it. The amplifier and filter do this. Active filter circuits have amplifiers incorporated in them. We can consider the VCA and VCF as members in the same family, the family of audio-modifier modules.

The voltage-controlled signal that enters the filter symbol from below fixes the cutoff frequency if the filter is low-pass (LP) or high-pass (HP). The control determines the center frequency for bandpass filters. Now we can obtain "colored noise." We choose a bandpass filter and use the keyboard to pick where the central frequency should be. See Fig. Q-7. If the central frequency is low, the filter lets a band or window of low frequencies pass. If a middle key is played, the noise band near the middle of the audio spectrum is highlighted. For the keys near the top of the keyboard, the noise band is centered on high frequencies, giving more of a "hiss."

The noise generator in Fig. Q-7 sends out "white noise" to the VCF. The VCF filters out frequency components of the noise, producing an output of "colored noise." Since we are using a bandpass filter, you may carefully pencil in BP to the lower left of the letters VCF inside the filter triangle. This reminds us to use the correct filter when we look up our "recipe" for interesting colored-noise effects in the future, i.e., Fig. Q-7. When a key is released, the control voltage corresponding to the key just released is still going to the VCF. This is due to the sample-and-hold characteristic of the KBD. Since the noise keeps sending out an audio signal, you keep hearing the filtered noise. You can use the VCA and ADSR, as we will show, to control the shape or envelope of the sound. Different settings on the ADSR then provide for a rich variety of noise effects.

Fig. Q-7. Synthesizing "Colored Noise."

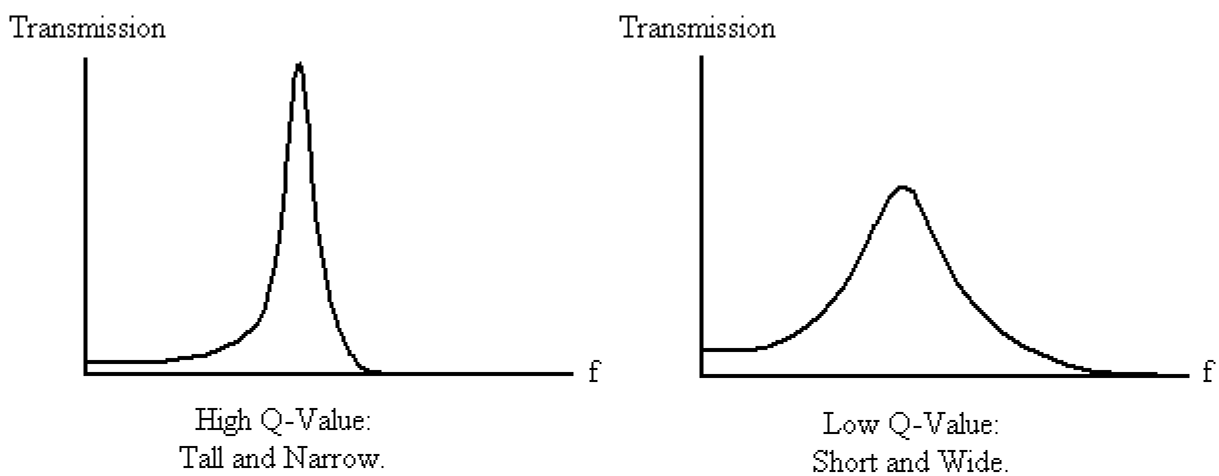


A special kind of bandpass filter can pass only a very narrow band of frequencies. This filter is called a *resonance filter*. It is essentially the resonance-tuner circuit we encountered in the AM radio; however, now we are dealing with audio frequencies. Our first encounter with resonance involved mechanical resonance very early in this text. Fig. Q-8 presents us with the familiar resonance curve again. But this time, two graphs with different features are given. Both are in the family of resonances. Specific choices for circuit elements can give the usual tall and narrow resonance-response curve or a short and wide one.

In radio electronics, a tuner with a tall and narrow response band is said to have much selectivity. The resonance circuit is very selective in its response. If the incoming frequency is not within a very narrow band of frequencies, there is very little or no response. This is desired since neighboring stations aren't picked up at the same time. Such a tuner is also more sensitive since the response at resonance is so great. This is another desired feature in tuner resonance circuits.

Resonance filters that are tall and narrow are said to have a high *Q-value* (Quality-value or Quality-factor). They are very selective in the frequencies that they pass. They also amplify these special frequencies very much. So the filters can be said to be sensitive to the frequencies near the resonance frequency.

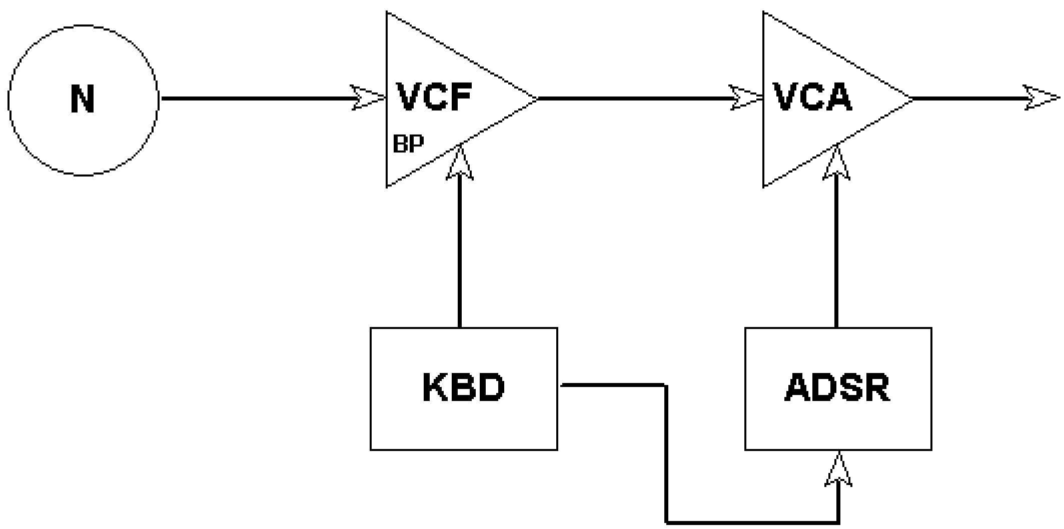
Fig. Q-8. Resonance Filters.




A resonance filter with a high Q-value passes a narrow band of frequencies. The emphasis of such a narrow band of frequencies produces a dull tone in the noise. When you whistle, especially not so good, there is a lot of noise mixed in with the whistling tone. A group of such whistlers is even a better example. We can use a narrow bandwidth filter to synthesize a group of whistlers. Fig. Q-9 gives the arrangement. We need the VCA and ADSR now in order to cut the sound off as we release the keys. In this way, we can play a tune.

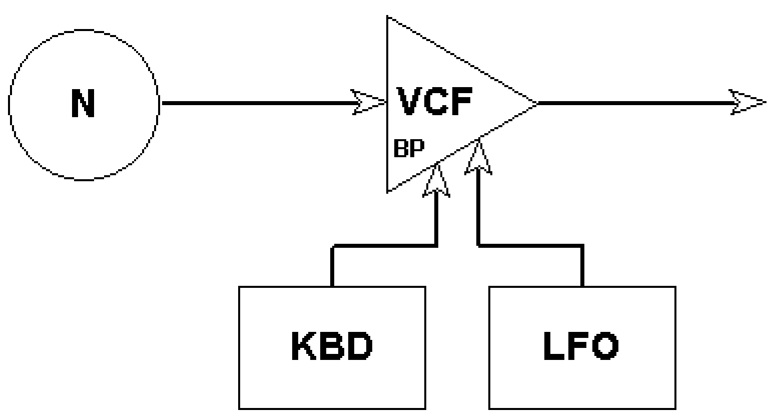
The key on the keyboard determines the central frequency of the bandpass filter in Fig. Q-9. If the bandpass filter is a resonance filter with a high Q-value, the filter can narrow the broadband white noise down to noise in the neighborhood of the resonance frequency of the filter. A tone with surrounding noise is produced. We approximate a group of whistlers, where noise comes from the air rushing in the mouth along with the whistling tone. We can synthesize a group whistling the tune *The Bridge on the River Kwai*. The VCA and ADSR supply the amplitude shaping of each whistled note.

Fig. Q-9. Synthesizing a Group of Whistlers (BP Filter with High Q-Value).




The arrangement in Fig. Q-10 below produces howling wind. It does not need a VCA and ADSR since the sound may continue on its own in this case. The KBD determines the central frequency for the bandwidth and the LFO shifts the entire bandwidth up and down, giving the howling-wind effect. Playing different keys gives variety to the sound.

Fig. Q-10. Synthesizing Howling Wind.

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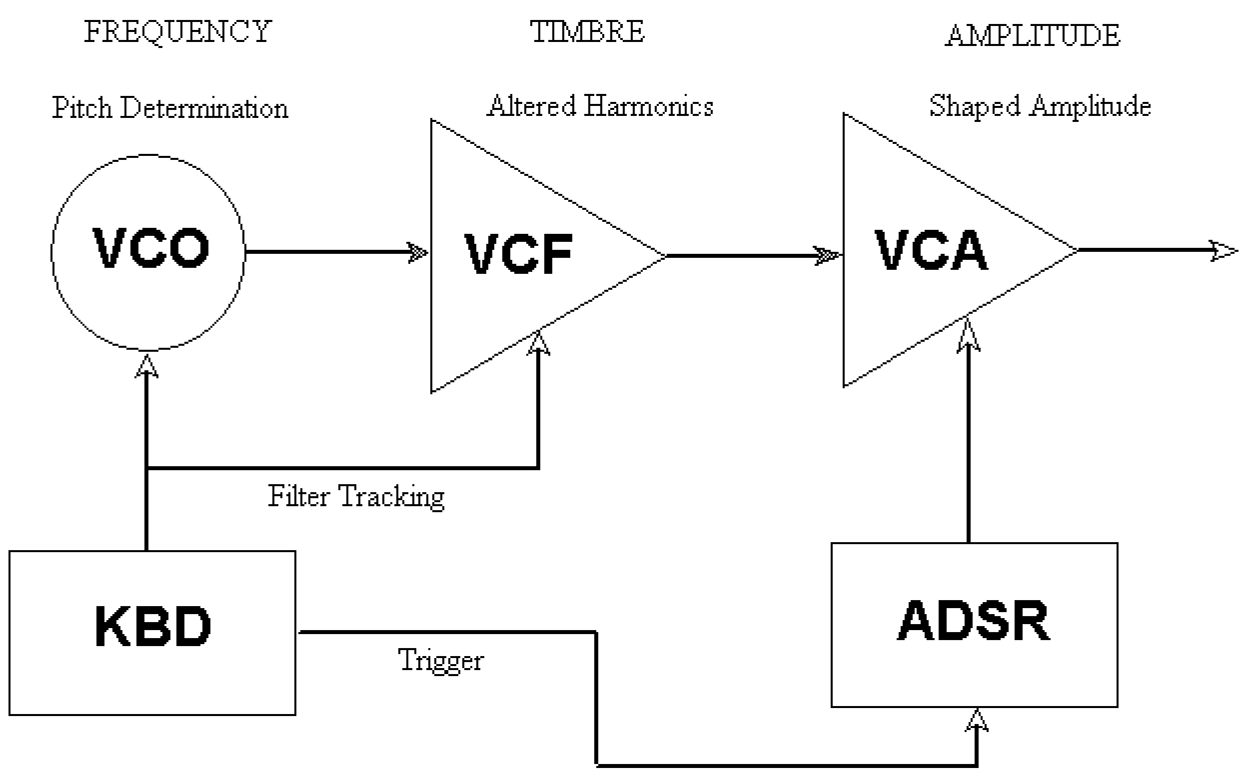
The most basic set of synthesizer modules for producing a musical tone consists of the following five modules: the VCO, KBD, VCA, ADSR, and VCF. The other two modules we studied, the LFO and N are used for special effects. The LFO can add tremolo or vibrato effects. Noise can be employed to synthesize explosions. The five modules needed for producing musical tones are depicted in Fig. Q-11 with their proper relationships to each other. Fig. Q-11 serves as an excellent review of modular components. It also introduces one new concept, filter tracking.

Fig. Q-11. The Standard Modular Arrangement for Producing a Musical Tone.




First we introduced the VCO and KBD. The VCO produces the audio signal with a frequency determined by the KBD. Think of these two modules working together as a pair. They address one of the three basic characteristics of a periodic tone, the frequency. The other two fundamental characteristics are the amplitude and timbre. The amplitude shaping is accomplished by the VCA and ADSR. Consider these as a pair working together. The amplitude shaping gives us the playing of a single note. Otherwise, the sound would continue indefinitely. The shaping of the third main aspect of a periodic tone, the timbre, is accomplished by the filter. However, it needs a control partner too. It uses the KBD. The KBD controls both the VCO and VCF.

There is good reason for the KBD to control both the VCO and VCF. If the cutoff frequency for the filter were to be fixed by some other control source, then some tones might be totally cut out. As you played up the scale, a low-pass filter could cut your high frequencies off. You want the filter cutoff frequency to follow you.

A specific example will illustrate this important point. Consider using the pulse train as the oscillator waveform. This is set manually before playing the synthesizer. The pulse train has a Fourier spectrum where each harmonic is present with equal amplitude. Consider also choosing a low-pass filter and an appropriate fixed-control voltage (from a power supply) so that the filter lets through the first three harmonics of the pulse train when we play *Do*. We obtain a unique sound, a pulse train with only the first three harmonics. Now if we start playing up the scale (*Do*, *Re*, *Mi*, etc.) the frequency of our pulse train gets higher and higher. It quickly gets beyond the low-pass filter cutoff and nothing comes through at the higher end of the scale. Playing up the scale and having your sound disappear is not good.

Now if the filter cutoff can move up the scale with us, then the filter can keep passing the lower harmonics. As the fundamental gets higher in frequency going up the scale, so does the cutoff frequency of the filter. To enable the filter cutoff to move with the note we play, we simply tap off the KBD control voltage and send it to the filter in addition to sending it to the VCO. The filter can now track our base frequency. With filter tracking, we preserve the filter's ability to modify our pulse train over the entire keyboard.

Even with filter tracking, the filter will not have exactly the same effect on our pulse train everywhere along the scale. Maybe an additional harmonic gets through here and there. However, the basic modification of passing lower harmonics is preserved. Timbres on real instruments change somewhat at low and high ends of the musical scale anyway. So we should not be too hard on our filter if it also varies somewhat in how it shapes the spectrum for different notes.

Note how the arrangement in Fig. Q-11 has three main vertical sections. The first, consisting of the VCO and KBD, focuses on frequency. The second region, consisting of the VCF with filter tracking made possible by voltage control from the KBD, is concerned with timbre. The third region, consisting of the VCA and ADSR, attends to the amplitude. The modification of the three essential features of periodic tones is accomplished by voltage control in each case. Note the first two letters "VC" for three of the modules. The trio of voltage-controlled modules reflects the fundamental nature of periodic-wave characteristics: frequency, timbre, and amplitude. To control these by voltage is the landmark discovery of the music synthesizer. Finally, see Figs. Q-12a and Q-12b, which introduce the LFO in order to give the synthesized musical tones a tremolo or vibrato effect.

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Fig. Q-12a. Adding Tremolo to the Standard Arrangement.

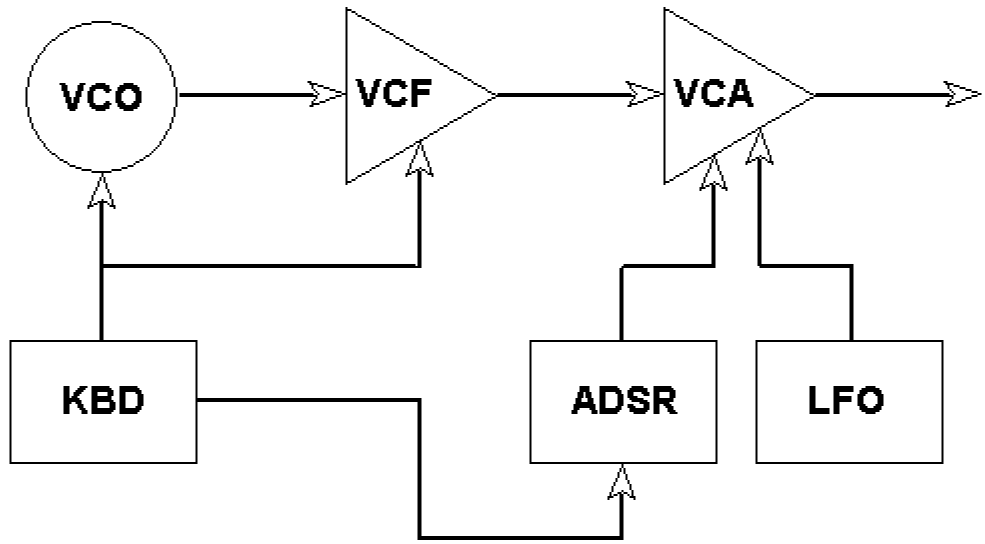
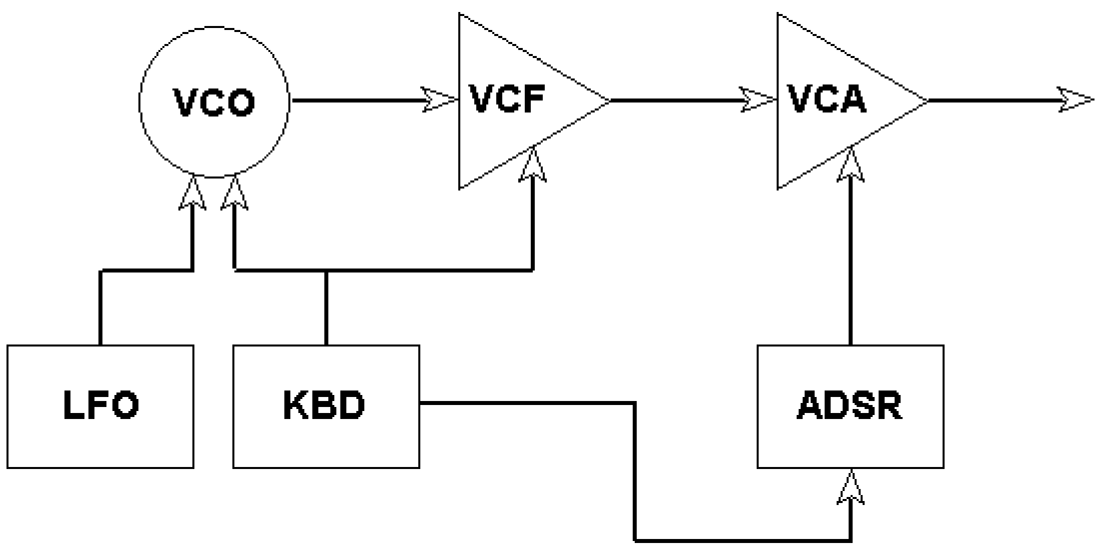



Fig. Q-12b. Adding Vibrato to the Standard Arrangement.

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