

Chapter 27

Electronic Music

In the broadest terms, the title “Electronic Music” could mean many different things. It could refer to electronic recording of music or to electrified musical instruments like the electric guitar. It could include computer-aided music composition or electronic production of a hard copy of a score. As commonly understood, however, electronic music refers to the electronic synthesis of performed music.

The idea of electronic music stems naturally from the idea of recorded music, either analog or digital. Imagine that you have in your hands a tape recording of a musical performance. You know that the music is entirely captured in the sequence of magnetization stretched out along the tape. It might then occur to you that if there were some way to duplicate that sequence of magnetization, starting from scratch, the original musical performance would not be necessary. Alternatively, imagine that you are holding a compact disc. You know that the music is entirely represented by a long string of ones and zeros on the disc. If you had a computer program that could create the same sequence of ones and zeros, you would have the music, even though it might never have previously existed in any acoustical form. These are the ideas of electronic music— analog and digital.

27.1 Analog Synthesizers

As you know, the first step in recording music is to use a microphone to convert an acoustical signal into an electrical signal. The electrical signal can be perfectly represented by a graph showing the electrical voltage as a function of time. The variations of voltage with time are analogous to the original variations of pressure with time. Because of this analogous relationship, the electrical signal has evident musical value. The goal of the analog synthesizer is to create an electrical signal with musical value without having to record it. Instead, the musician creates the electrical signal from a collection of electronic signal generating and processing circuits.

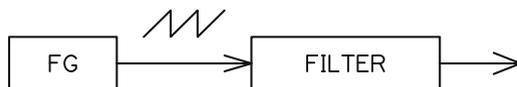


Fig. 27.1 An attempt to synthesize a violin tone using an analog patch of a function generator making a sawtooth wave and a filter with resonances

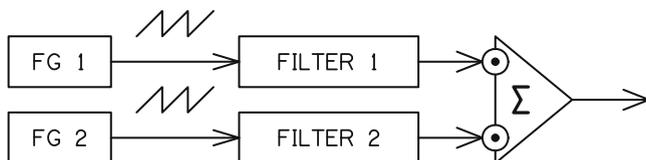


Fig. 27.2 Two tones can be added in a mixer (indicated by Σ to simulate a duet of instruments. The mixer adds the two voltages—more or less depending on the settings of the volume controls, shown by *circular knobs*

Chapter 4 on instrumentation introduced the function generator. The function generator creates a periodic electrical signal with a frequency that can be controlled by a knob on the front panel. For instance, the function generator can create a sawtooth wave. In fact, the sawtooth wave would not seem to be so very different from the wave of a violin sound. (See Fig. 25.4.) Both waves are periodic and both have a complete set of strong harmonics. If you put the fundamental frequency in the right range, perhaps you could use the sawtooth waveform to simulate a violin. However, you will recall that the body of the violin has resonances that emphasize harmonics having particular frequencies. This effect contributes in an important way to the violin sound. Unfortunately for our electronic musical experiment, the sawtooth wave does not have such emphasized harmonics. But there is no need to be discouraged, because it is possible to filter the sawtooth waveform with an electronic filter having resonances. Then the electronic filter changes the spectrum of the sawtooth to simulate the way that the violin body filters the spectrum of vibrations from the bridge. Thus, a first attempt at synthesizing a violin looks like the patch in Fig. 27.1. A *patch* is just a pattern of connections among modules.

The flexibility of analog electronics becomes evident if you want to generate the sound of two violins playing together. You only need to get another function generator and another filter and add the signals in a mixer. The mixer will add the two tones in a linear way, just like the air adds the tones from two violins. To control the levels of the two synthesized tones, there are volume (gain) controls on the inputs to the mixer.

Figure 27.2 shows two signals being added, but there is no real limit to the number of signals that could be added together. The mixer might have a dozen inputs, allowing you to simulate a violin chorus if you had enough function generators and filters.

At this point, however, your violin synthesis patch is not yet a satisfactory instrument. A real violin has a precise and flexible way of controlling the fundamental

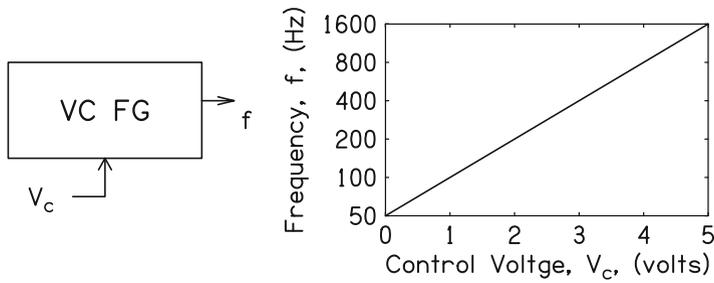
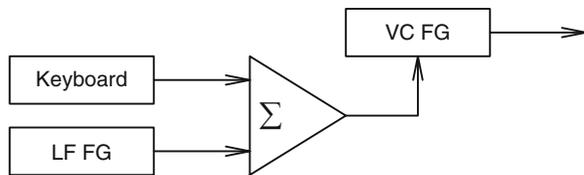


Fig. 27.3 The frequency of a voltage-controlled function generator (VCFG) depends on the control voltage inserted into the control port

Fig. 27.4 The frequency of the function generator (VCFG) is controlled both by the keyboard and by the low-frequency function generator (LFFG)



frequency of the tone. Precise control of the frequency is needed for melody, and the flexibility of the pitch is an essential part of artistic expression in violin playing. Your patch has none of that. It only has the knob on the front of the function generator to control the frequency. When you think about frequency control, you discover that you have real problems.

Because you are making a synthesizer, you would like to control the frequency with a keyboard. But you recall from Chap. 25 that the violin is played with vibrato, and therefore, the frequency control will need to incorporate the slow frequency modulation (FM). Evidently you need both kinds of control at once. To solve this problem you need to completely redesign the function generator. You need to make it voltage controlled. A voltage-controlled function generator (musicians often call it a voltage-controlled oscillator, or VCO) has a fundamental frequency that depends on a voltage that is put into a control port. If the voltage into the control port is low, the frequency is low. If the control voltage is high, the frequency is high (Fig. 27.3).

The voltage-controlled function generator allows a great deal of flexibility in pitch control because control voltages can be summed in a mixer, just as signal voltages were summed. Figure 27.4 shows how the frequency of the VCFG can be controlled in parallel by a keyboard (to play different notes) and by a low-frequency sine wave from another function generator (for vibrato). Voltages from the keyboard and from the low-frequency sine-wave function generator (LFFG) are summed to make a control voltage.

So far, so good. We can synthesize the tone of a violin (or two violins). We can control the frequency of the tone with a keyboard and give that tone realistic vibrato. There is a problem though—we cannot turn the tone on and off! As our

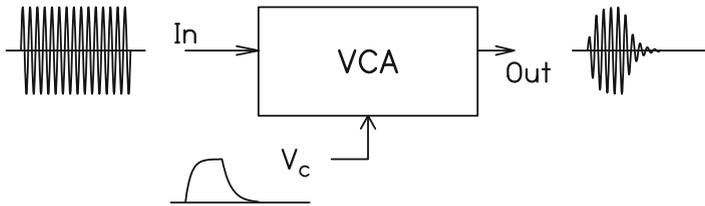


Fig. 27.5 The voltage-controlled amplifier (*VCA*) multiplies the input voltage by the control voltage (V_c) to produce an output voltage. Here, an input signal that is indefinitely long is turned on and off, and its amplitude is given a realistic shape by the envelope voltage (V_c) that is inserted into the control port for the *VCA*.

patch of modules stands now, the tone is always on. We cannot just turn the tone on and off with a switch because such an abrupt onset and decay would not resemble the attack and decay of a violin tone. At this point we need a *voltage-controlled amplifier* (*VCA*) and a device called an envelope generator, as shown in Fig. 27.5.

The *VCA* has a signal input voltage, a signal output voltage, and a control input voltage. The signal output is the product of the signal input and the control input. Therefore, if the control input is 0 V, the output is zero. Now we can turn the tone off. If the control input rises in a gradual way and then dies away slowly, the output signal has a gradual attack and then fades out slowly. It is the role of the *envelope generator* to produce a slowly moving voltage that leads to a realistic attack and decay. The envelope begins its attack when the musician presses one of the keys of the keyboard.

Voltage control was a powerful idea in the early days of electronic music synthesizers because voltages can be easily and cheaply manipulated. They can be switched on and off, amplified, attenuated, inverted, summed, or distorted. A series of control voltages can be automated to produce a sequence of musical control gestures. Therefore, many different signal processing parameters were given voltage control. Most important were the voltage-controlled function generator (oscillator), the *VCA*, and voltage-controlled filter (where the cutoff frequency or passband frequency was determined by a control voltage). The voltage-controlled modules could be chained indefinitely. The vibrato example shown above was a short illustration of that.

The voltage-controlled analog synthesizer is no longer a mainstream instrument. It is awkward to use and expensive because it has a lot of front-panel hardware. Nevertheless, it is an important instrument because the functions of its voltage-controlled modules provided a common language and a useful framework for thinking about musical signal synthesis. These ideas are now implemented in digital synthesizers.

27.2 Digital Synthesizers

In a modern instrument, the modular functions are accomplished digitally. Signals, as such, do not exist in the digital synthesizer. Instead, signals are computed, and they remain in the form of digital numbers until finally converted to a voltage by a digital to analog converter. For example, while an analog synthesizer would add two voltages in a summer (perhaps two violin tones), the digital synthesizer adds two long sequences of numbers. Each sequence represents an instrument; each number represents an instantaneous value of the waveform produced by the instrument.

From the outset, digital methods are clearly promising. First, digital methods are fast. If there is a computational engine capable of millions of operations per second, then many operations can be done to generate each successive data point in the output. Second, digital methods can make use of computer memory. Memory can store both musical waveforms and control data, such as the times for turning notes on and off and the dynamics of a performance.

Speed and memory make a big difference. While an analog synthesizer is limited to one or two simultaneous voices, the speed of a digital synthesizer allows it to be truly polyphonic. The instrument can produce as many simultaneous notes as the musician can play on the keyboard. While an analog function generator is limited to a few simple waveforms, a digital memory can store waveforms digitally—perhaps recorded from real musical instruments. Pre-recorded real instrument sounds become useful when other synthesis techniques fail. For example, it is difficult to synthesize a convincing piano sound by any other means.

Because the digital synthesizer keeps all the music in memory before converting it to an analog voltage, it is automatically capable of performing signal processing techniques that add together multiple versions of the same signal with various delays. An application that immediately comes to mind is artificial reverberation. Without reverberation, synthesized music is weak. Artificial reverberation of some kind is always needed, and digital methods are ideal for this task. There are other applications of delay-and-add processing that came out of rock and roll studios. One is the technique called “chorusing” that thickens a musical voice by adding clones. Another is a technique called “flanging” that varies the amount of delay to produce a sonic effect described as “spacy.”

The digital synthesizers that appear on stage at concerts are real-time performance instruments with a keyboard that can be played like a piano. The user can select from a few hundred different waveforms representing musical instruments or sound effects. Such sound “samples” are stored in waveform memory. Some synthesizers permit the user to record sounds into sample memory, to be played back later with different pitches. But the digital synthesizer is more than just a reproducer of sampled sounds. The recorded waveform samples can be processed as they are played back. Vibrato, filtering, spatial effects, and diverse forms of modulation can be added.

A digital synthesizer also includes a *sequencer*, which is a memory for musical gesture data. Such data can tell the signal generators to play the right notes at the

right times with appropriate expression—level, level variation, vibrato, and pitch bend. The sequencer can store away enough gestural and performance data that it can play all the different parts of an entire piece of music by itself, once it is programmed to do so. Including the human musician in a live performance is still regarded as a nice touch, however. What is often done as a compromise is to preprogram rapid sequences of notes—arpeggios or riffs—so that pressing a particular key on the keyboard unleashes the entire sequence.

27.3 Musical Instrument Device Interface

The *musical instrument device interface*, or MIDI, is a data protocol that allows different electronic music instruments to communicate with one another. At a concert you will see a musician playing a keyboard instrument. It does not follow, however, that the instrument that he is playing is the instrument that is making the sounds! Quite possibly, the keyboard synthesizer is just being used as a control device to send gestural data to another synthesizer to make the sounds. The other synthesizer might be a box of electronics in a rack somewhere, or it might be a virtual synthesizer, which is a computer program running on a general purpose personal computer with a sound card.

The ability to send musical performance data around a stage or around a studio is made possible by the MIDI. Each musical device in the loop has a channel address, and data intended for that instrument are preceded with that channel number. Therefore, the MIDI connection requires only a single wire, running daisy-chain fashion among all the synthesizers or control devices. The intention of the MIDI protocol is to transfer all musically relevant information. There are set-up commands that tell a synthesizer to play a particular voice, such as a tom-tom or clarinet. There are performance data that turn notes on and off, and there are expressive data from keyboard pressure or pitch-bend wheels or foot pedals.

Because MIDI data are only control data, and not actual waveforms, MIDI data do not require a tremendous amount of memory and can be transmitted rapidly. MIDI data can be displayed on a computer monitor screen and can be edited to improve the performance. If you play a great riff except for one mistake, it is easy to correct the mistake with a computer editor and keep everything else.

The MIDI standard is an open standard, which means that any engineer can produce a musical instrument that reads and writes MIDI code. An important consequence is that different controllers can be created—replacing or augmenting the keyboard. Control technologies that resemble traditional musical instruments make it possible for many musicians to synthesize music digitally. It is even possible to synthesize sound based on a performer's brain waves, as measured by an electroencephalographic monitor, though the degree of control may not appeal to the performer or any other listener.

Science, Technology, Music, and Musicians

Electronic music is, in a sense, an ultimate in the application of technology to music. In one way or another it makes use of all the science to be found in this book. Making music electronically, either analog or digital, leads to an unprecedented opportunity for analysis and control of musical parameters.

In the early days of electronic music, people were impressed by the novelty of the sounds, and there was great interest in “what the electronic music synthesizer could do.”

A perspective on this matter was given by Dr. Robert A. Moog (1934–2005), one of the pioneers of analog music synthesis. Bob Moog emphasized that at every period in history making music has involved the technology of the time. Ultimately, music was not made by the technology, it was made by musicians.

In October of 1974, Moog gave a talk at a meeting of the American Physical Society in Buffalo, New York. As he always did in his talks, he illustrated his points by playing compositions made on one of the synthesizers manufactured by his company. As I recall, he played a portion of *Snowflakes are Dancing* by Isao Tomita. At the conclusion, an enthusiastic member of the audience yelled out, “Oscillator, Oscillator!”

Without hesitation, Moog replied, “The next time I hear a violin concerto I am going to yell out, ‘Cat, Cat!’” His point was that the electronic composition was no more played by the electronics than the violin concerto was played by catgut.

In the end, whatever the science or the technology, music is made by musicians. Musicians can take a couple of sticks and a rusty bucket, and use this “technology” to make music. The rational approach to musical sound adopted in *Principles of Musical Acoustics* is valuable intellectually. It may even help a musician better understand the principles of the craft. However, music surpasses the intellectual; it speaks to us on a deep and personal level. That is its real value.

Exercises

Exercise 1, Design this patch

The output of a voltage-controlled amplifier module (VCA) is given in terms of the input to the module by the following formula,

$$v_{out} = v_{in} \times (v_c/5) \quad (v_c \geq 0) \quad (1)$$

$$v_{out} = 0 \quad (v_c < 0) \quad (2)$$

where v_c is the control voltage in volts. Thus when the control voltage is zero, there is no output. When the control voltage is 5 V, the output is equal to the input.

Draw a patch including two function generators and a VCA to generate an amplitude-modulated signal, as described in Chap. 21.

Exercise 2, Digital speed

Imagine a digital synthesizer that performs 100,000,000 operations per second. It generates a signal at a sample rate of 44,100 samples per second, the sample rate of the compact disc. Show that this synthesizer can perform more than 2,200 operations for every output sample.

Exercise 3, Emulation

As a relatively new art form, electronic music is still trying to decide what it wants to be. Recently designers have worked hard to synthesize the sounds of traditional acoustical instruments. Others say that this is a mistake. They think that the role of electronic music should be to create new sounds. What do you think?

Exercise 4, Wheels

Many synthesizers have two controllers shaped like wheels to be controlled with the musician's left hand. (a) One of them controls the depth of the vibrato. (b) The other is able to bend the pitch of a note. Why would one go to the trouble of providing such elaborate frequency control?

Exercise 5, Computer application

Is a general purpose computer, like a PC, more naturally a sequencer or a synthesizer?

