one must remember that the arts succeed where computers fail in elevating the human being in us all. The development of electronic music—itself a by-product of technology—exemplifies everything about being human that the arts can offer.

Chapter 1

WHAT IS ELECTRONIC MUSIC?

The field of music is full of uninformative labels and categories. Electronic music has not escaped this phenomenon. During the heyday of institutionalized electronic music in the '50s, even the founders of the music had difficulty agreeing on what to call it. Schaeffer and Henry called their combination of synthetic and natural sounds "musique concrète." Eimert and Stockhausen called their music of purely synthetic origins "elektronische Musik." Varèse called his combination of synthetic and processed natural sounds "organized sound." Luening and Ussachevsky called it "tape-music."

The situation is no less confusing today. Try and explain the differences between ambient, illbient, minimalism, new age, space music, electronica, techno, environmental, avant-garde, downtown (in New York), proto-techno, electro, Krautrock, world, dub, trance, house, acid house, rave, and just plain old electronic music. Most of these so-called genres exist as points on a single continuous spectrum of music that wouldn't be possible without electronics. Trying to define them any further than that is unhelpful.

I decided not to pigeonhole works of electronic music into those kinds of uninformative genres. Instead, it makes more sense to me to discuss the music from the standpoint of composition: the aesthetic and technological approaches used by a composer to work with the sound material. This requires an understanding of the technology that aids the composer, for in the field of electronic music the creative act is securely tethered to the equipment. A discussion of musique concrète must also be a part of a discussion of tape recorders, tape loops, and the kinds of sound manipulation that can take place because of tape editing. Other technology and approaches that drive the nature of a composer's work include process music, turntablism, and tools that can be used for real-time electronic music production in live performance. By discussing the music in this way I hope to acknowledge the unavoidable influence of technology on the composer while at the same time providing a framework within which different approaches to composition can be illuminated. It also allows for the easy grouping of works of similar conceptual and technical origins so that they can be compared and contrasted.

The stuff of electronic music is *electrically produced or modified sounds*. A synthesizer, sine wave generator, and a doorbell all use electrically produced sounds. An amplified violin connected to a wah-wah pedal, or a voice being embellished by electronic reverberation, are examples of ways to modify sounds.

This is perhaps as broad a definition as one can have of electronic music short of admitting that everything we listen to can be defined in this way. The lines are often blurred between sounds that originate from purely electronic sources and sounds from the real world that are synthetically modified. But I will use two basic definitions that will help put some of the historical discussion in its place: purely electronic music versus electroacoustic music.

Purely Electronic Music

Purely electronic music is created through the generation of sound waves by electrical means. This is done without the use of traditional musical instruments or of sounds found in nature, and is the domain of computers, synthesizers, and other technologies. It is the realm of programs, computer displays, and "virtual" instruments found in software.

Ensembles for Synthesizer (1961–63) by Milton Babbitt (b. 1916) is an example of purely electronic music. It is a twelve-tone piece exploring different "ensembles" of rapidly changing pitches, rhythms, and timbres. It was composed using the RCA Music Synthesizer at the Columbia-Princeton Electronic Music Center. *Switched-On Bach* (1968) by Wendy Carlos (b. 1939) is an example of purely electronic music in which Carlos performs keyboard music of Bach using only the Moog synthesizer.

Purely electronic music can be made through either *analog* or *digital* synthesis. The difference between the two merely lies in the way electricity is controlled. There are no aesthetic differences between the outcomes, and the listener will probably not be able to tell the difference.

In analog synthesis, composers work with continuous electrical current that is *analogous* to its corresponding sound waves. The sound begins as an electric current (alternating current, or AC). The vibrating pattern of the current can be controlled by the composer to create regular or irregular patterns. This current is then fed to an amplifier and loudspeakers, which convert the electrical oscillations into air pressure waves that can be detected by the ear. The resulting sound waves vibrate at the same rate as the electrical waves produced by the electrical sound source. The vibrations of the electric current are controlled by triggering devices such as rotating dials and piano-style keyboards. Analog sounds can be generated by something as simple as a buzzer or sound-wave oscillator, or by an instrument designed more specifically for musical applications such as an electric guitar or analog synthesizer.

Making sound digitally requires computer circuitry that can generate sound waves. Home computers, toys, digital synthesizers, and video games do this through the use of sound chips. Instead of working directly with the control of continuous electric current, a sound chip represents sound waves as binary information, coded into a series of "on" and "off" electrical pulses. This bitstream represents sounds using the same principles that a computer uses to represent numbers or letters of the alphabet. Different pitches are represented by different codes. Because human hearing is an analog process, digital signals must be converted to analog signals before they can be heard. To make the sound patterns audible, the computer converts the codes into an analog form of electrical current that can be amplified and used to operate a loudspeaker. This is done through what is called a digital-to-analog converter. Once the digital codes are converted into continuous electric current and fed to a speaker system, they sound the same as sounds produced through conventional analog means. The reverse process can be used to get analog sounds into a computer for digitization; they are converted using an analog-to-digital converter and then controlled by the computer.

The benefits of digitally generated sound synthesis are many. Like anything else that can be done on a computer, sounds can be controlled and organized with unprecedented ease, in comparison to the rigors of manipulating analog sounds on tape. Digital sounds can be cut and pasted, modified using special effects, made louder or softer, and structured to precise time measurements. Digital sound has the added benefit of being devoid of hiss and other audio artifacts of analog tape recording. The music that results can be copied directly to an audio CD for listening, storage, and distribution.

The term "synthesis" refers to the process of constructing sounds using electronic, or synthetic, means. The music synthesizer is a device designed to generate purely electronic sounds by analog or digital means. Prior to 1980, most commercially available synthesizers were analog.

Electroacoustic Music

Electroacoustic music uses electronics to modify sounds from the natural world. The entire spectrum of worldly sounds provides the source material for this music. This is the domain of microphones, tape recorders, and digital samplers.

The term "electroacoustic music" can be associated with live or recorded music. During live performance, natural sounds are modified in real time using electronics. The source of the sound can be anything from ambient noise to live musicians playing conventional instruments.

Cartridge Music (1960) by John Cage (1912–1992) is a work of electroacoustic music in which phono cartridges were used to amplify sounds that were otherwise nearly inaudible. *Rainforest IV* (1973) by David Tudor (1926–1996) used the amplified and processed sounds of vibrating objects freely suspended in the performing space. The sounds were amplified, filtered, mixed, and also recycled to make other objects vibrate.

The manipulation of recorded, naturally occurring sounds is the foundation of much electronic music. The classic art of composing electronic music using magnetic tape was not conceptually very different from what is called "digital sampling" today. The objective in each case is to capture sounds from the real world that can then be used, and possibly modified, by the composer.

The amplification of traditional musical instruments is a form of electroacoustic music, but for the purposes of this book such work only crosses the line into the realm of electronic music if the musician uses technology to modify the sound.

The interaction of live musicians playing electronically modified or processed acoustic instruments has been a popular approach with composers. In *Mikrophonie I* (1964) by Karlheinz Stockhausen (b. 1928), the sounds of a tam-tam are picked up by two microphones, amplified, and processed through electronic filters. *Wave Train* (1966) by David Behrman (b. 1937) which threw away all established techniques for playing the piano, consisted of controlled feedback caused by guitar pickups placed on the strings of a piano. *Superior Seven* (1992) by Robert Ashley (b. 1930) used real-time digital processing to extend and embellish the notes played by a flutist.

Electronic music exists *because* it is conceived and created with electronic instruments. Does this make it different from other kinds of music? Don't we listen to it with the same set of ears?

Aaron Copland observed that "we all listen to music, professionals and non-professional alike, in the same sort of way—in a dumb sort of way, really, because simple or sophisticated music attracts all of us, in the first instance, on the primordial level of sheer rhythmic and sonic appeal."[1]

As attractive as this observation is, I will argue that we listen to electronic music with different ears, and a different state of mind. One day this will not be the case. Our taste and perceptual constructs will evolve to the point where music of non-acoustic origins will be treated with the same objectivity as all other music, in Copland's "dumb sort of way." But today, hardly fifty years into the recorded medium of electronic music, we have barely been able to get past the technology and think only about the music. Composer-technicians are still most at home in this field. Anyone who composes with synthesizers, software, and computers knows very well that the technology of electronic music has not yet reached the "appliance" stage. When it does, the necessities of *composing* will preoccupy composers instead of the necessities of *mechanics*, the knowledge needed to push the correct buttons and plug in the correct components.

Electronic music is not entirely alien to us. It shares many characteristics with other music. It is emotionally charged and designed to absorb one's attention. Even the most colorless music, stripped of all ornamentation, is fraught with emotional implications. Charles Ives took the twelve-tone composers to task when he wrote, "Is not all music program music? Is not pure music, so called, representative in its essence? Is it not program music raised to the *n*th power, or, rather, reduced to the minus *n*th power? Where is the line to be drawn between the expression of subjective and objective emotion?"[2] The listening experience is psychological and fluid, moving forward incessantly, demanding that we take notice or miss out.

Seven Reasons Why Electronic Music Is Different

The sound resources available to electronic music are unlimited and can be constructed from scratch. One of the key differences between electronic music and music composed for traditional instruments is that *its sonic vistas are limitless and undefined.* The composer not only creates the music, but *composes* the very sounds themselves. Herbert Eimert (1897–1972), one of the founders of the Studio für Elektronische Musik in Cologne, expressed the innate potential of electronic music this way:

> The composer, in view of the fact that he is no longer operating within a strictly ordained tonal system, finds himself confronting a completely new situation. He sees himself commanding a realm of sound in which the musical material appears for the first time as a

malleable continuum of every known and unknown, every conceivable and possible sound. This demands a way of thinking in new dimensions, a kind of mental adjustment to the thinking proper to the materials of electronic sound.[3]

Any imaginable sound is fair game. The composer can invent sounds that do not exist in nature or radically transform natural sounds into new instruments. For *Thema–Omaggio a Joyce* (1958), Luciano Berio (b. 1925) used tape manipulation to transform the spoken voice into a myriad of sound patterns eerily laced with the tonalities of human communication. In the piece *Luna* (from *Digital Moonscapes*, 1984), Wendy Carlos modeled a digital instrument whose voice could be modified in real time as it played a theme, metamorphosing from the sound of a violin to a clarinet to a trumpet and ending with a cello sound. This sound wasn't possible in the world outside of the computer, but became possible with her library of "real-world orchestral replicas" that the GDS and Synergy synthesizers allowed.[4] For *Beauty in the Beast* (1986), she took this experimentation a step further by "designing instrumental timbres that can't exist at all, extrapolated from the ones that do exist."*

Electronic music expands our perception of tonality. The accepted palette of musical sounds was extended in two directions. On one hand, the invention of new pitch systems became easier with electronic musical instruments. Microtonal music is more easily engineered by a composer who can subdivide an octave using software and a digital music keyboard than by a piano builder. On the other hand, electronic music stretched the concept of pitch in the opposite direction, toward less and less tonality and into the realm of noise. All sounds became equal, just another increment on the electromagnetic spectrum. Varèse sensed this early on and introduced controlled instances of noise in his instrumental and electronic music. Cage accepted the value of all sounds without question and let them be themselves:

> Noises are as useful to new music as so-called musical tones, for the simple reason that they are sounds. This decision alters the view of history, so that one is no longer concerned with tonality or atonality, Schoenberg or Stravinsky (the twelve tones or the twelve expressed as seven plus five), nor with consonance and dissonance, but rather with Edgard Varèse (1885–1965) who fathered forth noise into twentieth-century music. But it is clear that ways must be discovered that allow noises and tones to be just noises and tones, not exponents subservient to Varèse's imagination.[5]

* Wendy Carlos, interview with Carol Wright, *New Age Voice*, <www.newagevoice.com>, November, 1999, copyright 1999 by Carol Wright (June 18, 2001).

Electronic music only exists in a state of actualization. Igor Stravinsky (1882–1971) wrote that "it is necessary to distinguish two moments, or rather two states of music: potential music and actual music. . . . It exists as a *score*, unrealized, and as a *performance*."[6] You will rarely find an electronic work that can be accurately transcribed and reproduced from sheet music. It does not exist as "potential music" except in the form of notes, instructions, and ideas made by the composer. Conventional musical notation is not practical for electronic music. You cannot study it as you would a piece of scored music. Experiencing electronic music is, by its nature, a part of its actualization. The term "realization" was aptly adopted by electronic music pioneers to describe the act of assembling a finished work. Even those works that are transcriptions of conventionally composed chromatic music cannot be fully described on paper, because the elements of electronic instrumentation, sound processing, and performance defy standardization. A work of electronic music is not *real*, does not exist, until a performance is *realized,* or played in real time.

Electronic music has a special relationship with the temporal nature of music. "Music presupposes before all else a certain organization in time, a chrononomy."[7] The plastic nature of electronic music allows the composer to record all of the values associated with a sound (e.g., pitch, timbre, envelope) in a form that can be shifted and reorganized in time. The ability to modify the time or duration of a sound is one of its most fundamental characteristics. Traditional instrumental music, once recorded, benefits from a similar control over the manipulation of a real-time performance. The equivalency between space and time that Cage attributed to the coming of magnetic tape recording—and which can be extended to any form of analog or digital sound recording or even MIDI control signals—has the liberating effect of allowing the composer to place a sound at any point in time at any tempo.

In electronic music, sound itself becomes a theme of composition. The ability to get inside the physics of a sound and directly manipulate its characteristics provides an entirely new resource for composing music. The unifying physics behind all sounds—pitched and unpitched alike—allow a composer to treat all sounds as being materially equal.

Electronic music does not breathe: it is not affected by the limitations of human performance. As Robert Ashley learned about electronic music early on, "It can go on as long as the electricity comes out of the wall."[8] The arc and structure of the music is tolerant of extremes in the duration and flow of sounds. The ability to sustain or repeat sounds for long periods of time—much longer than would be practical for live instrumentalists—is a natural resource of electronic music. In addition to its sustainability, electronic music can play rhythms too complex and rapid for any person to perform. It can play with more than two hands at the same time. The composer is freed of the physical limitations of human performance and can construct new sounds and performances of an intricacy that can only exist as a product of the machine.

Electronic music springs from the imagination. The essence of electronic music is its disassociation with the natural world. Hearing is a "distance" sense, as opposed to the "proximal" senses of touch and taste. Listening engages the intellect and imagination to interpret what is heard, providing "only indirect knowledge of what matters—requiring interpretations from knowledge and assumptions, so you can read meaning into the object world."[9] Having little basis in the object world, electronic music becomes the pulse of an intimate and personal reality for the listener. Its source is mysterious. "It is thought, imagined and engraved in memory. It's a music of memory."[10] In these ways, the human being becomes the living modulator of the machine product, the circuitry dissolves into the spirit of humanness that envelops it.

Chapter 2

ELECTRONIC MUSIC RESOURCES

Electronic music is an art that marries technology and human imagination. While becoming an electrical engineer is not a prerequisite for making or listening to electronic music, some background on how the music is produced can improve one's appreciation for it. Anyone with the added inclination to become a soldering composer should certainly take notice of the material attributes of sound.

The Components of Sound

Sound is produced by air pressure waves that cause the eardrum to vibrate. These vibrations are converted by auditory nerves into impulses that the brain recognizes as sounds. If the wave vibrates in a regular pattern, it is perceived as a pitched sound, such as those used in music. If the wave does not vibrate in a regular pattern, it is perceived as unpitched sound or noise.

The science of musical acoustics developed during the latter half of the nineteenth century in tandem with general discoveries in the field of electricity. The scientist Hermann von Helmholtz (1821–1894) was largely responsible for this work, with his landmark 1862 paper "Sensations of Tone." In it, he demonstrated that musical sound could be analyzed according to a few basic physical principles. Using combinations of tuning forks to illustrate his point, he showed that the quality (or timbre) of a tone was reliant on the intensity, order, and number of harmonics (overtones and partials) present in the note. A single musical note was not so simple after all. Helmholtz showed that it actually consists of a base, or fundamental, tone accompanied by related vibrations (harmonics) above the pitch of the fundamental, which create timbre, or tone color. Timbre is what distinguishes the sound of a violin from the sound of a piano, even though both instruments might be playing the same note. Every instrument exhibits its own unique mixture of harmonics. This theory suggested that sound could be analyzed by its component parts.

Helmholtz's analysis of the components of sound had a profound effect on many inventors and composers. The instrument builder Thaddeus Cahill cited Helmholtz in devising his technology for synthesizing sound. An understanding of the wave structure of sound led to a robust reassessment of tonal systems used by composers. Our entire understanding of consonance and dissonance stems from this scientific work. Helmholtz's theories also inspired a new, rational approach to analyzing sounds of all types, including noises. The Futurists transformed this science into a rational categorization of sounds into different types for the purpose of composing with them. Varèse's mentor, the musical visionary Ferruccio Busoni (1866–1924), saw in the scientific understanding of musical sound the possibility of a scientific or technical instrument for making new sounds. He wrote in 1907:

> Suddenly, one day, it seemed clear to me that the full flowering of music is frustrated by our instruments. . . . In their range, their tone, what they can render, our instruments are chained fast, and their hundred chains must also bind the creative composer.[1]

All of these people had set the scene many years before the arrival of composer John Cage. What Cage brought to the affair that the others did not was an artistic clarity about the nature of creating music. He did this partly by removing his emotions from the process and objectively examining the materials of music. He sought ways to let sounds be themselves, allowing the listener to provide whatever emotional or intellectual context he or she needed to assess the result. His approach was not unlike that of a scientist studying a natural phenomenon. He observed, measured, and experimented to carry out musical hypotheses in the form of compositions.

Like Helmholtz, Cage was fascinated by the constituent parts that make up sound. In 1937, he gave a talk to an arts society in Seattle in which he suggested that music should be defined by its four basic components: the timbre ("overtone structure"), frequency, amplitude, and duration of sounds.[2] By 1957 he had added a fifth component to the list: the "morphology," or envelope, of the sound, otherwise known as its attack and decay characteristics, or "how the sound begins, goes on, and dies away."[3]

When Cage first proposed these ideas he also related them directly

to the potential of using electronic musical devices to broaden our sound spectrum and create a new kind of music. The special nature of "electrical instruments" was that they provided total control over the principal components of sound. In perhaps his most prophetic statement, Cage said in 1937, "I believe that the use of noise to make music will continue and increase until we reach a music produced through the aid of electrical instruments which will make available for musical purposes any and all sounds that can be heard." (*Silence*, pp. 3–4) Cage was by no means working in aesthetic isolation. He had the benefit of knowing and learning from several key figures in contemporary music, including Edgard Varèse, Henry Cowell (1897–1965), and Arnold Schoenberg (1874–1951). But in analyzing sound according to the five basic parameters—timbre, frequency, duration, amplitude, and envelope—Cage defined the common denominators by which all sound can be described. What set Cage apart was that he used these essentially scientific principles to rewrite the definition of music. Because all sounds are composed of the same primary components and because music *is* sound, then it must follow that all sounds can be defined as being musical.

Understanding the five components of sound is helpful for the appreciation of any music. They are especially pertinent to electronic music because the composer and musician are often working with direct control over these aspects of what you hear.

- **Frequency:** the pitch of a sound. Specifically, it is the number of vibrations per second, which, when in the audible range, are detected as a certain pitch. In electronic music, this pitch becomes audible as an expression of the alternating electrical current that is used to vibrate the cone of a loudspeaker at a certain rate per second.
- **Amplitude:** the loudness or volume of a sound. Amplitude is conveyed by a loudspeaker by the distance that the speaker cone moves back and forth from its neutral position. This varies from frequency, which determines how fast the speaker cone vibrates, but not how powerfully it does so. With acoustic instruments, amplitude is controlled by the performer playing softer or harder—pressing the key, blowing the horn, bowing the strings, etc. In electronic music, amplitude is driven by the electrical power of an amplifier that makes electronically produced sounds audible.
- **Timbre:** the nature or quality of a sound, sometimes known as tone color. Timbre is what distinguishes the sounds of different musical instruments playing the same note. All sound waves are complex and contain more than just one simple frequency or fundamental tone. These additional wave structures are called such

things as partials, overtones, harmonics, and transients. If one pitch, or fundamental, predominates, then the sound can be related to a note on the musical scale. When there is more competition for dominance or there are very complex sets of overtones present, a sound may take on highly dense and unusual characteristics.

- **Duration:** the length of time that a sound is audible. Acoustic instruments have a limited ability to sustain sounds. The piano was even designed with a special pedal just for the purpose of letting notes linger longer. Electronic instruments have the innate ability to sustain a sound indefinitely, making duration a key element in composition. Duration is closely allied with the principles of the sound envelope.
- **Envelope:** the attack and decay characteristics of a sound—the way it begins, sustains, and ends. This is essentially the shape of the amplitude characteristics of a sound as it occurs over time. *Attack* refers to the beginning of a sound and how long it takes to reach its maximum loudness. *Sustain* is the length of time that a sound lasts at its peak loudness. *Decay* is the time it takes for a sound to drop off and end. Visually, the shape of a sound can be depicted as a ramp that goes up, levels off, and then goes down again. In electronic music, the envelope of a sound wave can be controlled with great precision.

Waveforms

Sound waves can be represented graphically by their two basic characteristics, *pitch* and *loudness*. In electronic music, pitch is referred to as *frequency* and is defined by the number of vibrations that occur each second (also known as hertz, or Hz). The loudness of a sound is its *amplitude*. In a diagram of a wave, amplitude is represented by the height of the wave.

A complex tone is composed of several sound waves. It will have a *fundamental frequency* and additional sidebands or overtones. The fundamental is the wave with the lowest frequency or the highest amplitude and thus dominates the combination of tones. Overtones add color to the sound, giving it character or timbre.

While most of the sounds we hear in electronic music are combinations of multiple waves or are specially treated for added tone color, it is possible to catalog a few basic waveforms, or waveshapes, that serve as the building blocks of the electronic music composer. Computer sound cards and music synthesizers provide electronic audio oscillators capable of generating any one of these waves in an approximately pure form.

- **Sine wave:** This is the simplest type of wave. Theoretically, it should contain no harmonics or overtones. Although some liken the sound of a sine wave to that of a flute, even the flute has more body and depth than a pure sine tone. The sine is a thin, precise tone, similar to a whistle.
- **Triangle wave:** A triangle wave is similar to a sine wave but has a number of harmonics, or sidebands, added. Its sound has more body and depth than a sine wave and a more hollow effect, like that of a flute, trumpet, or musical saw.
- **Sawtooth wave:** This waveform has a sharp, angular shape like the teeth of a saw. It has twice as many harmonics as a sine wave. It has a full, buzzing sound, like a reed instrument such as the saxophone.
- **Pulse wave:** This waveform has the same number of overtones as a triangle wave but the grittiness and reedy sound of a sawtooth. The waveform jumps instantly from the lowest point of its waveshape to the highest. When diagrammed, it consists only of right angles and is often called a square or rectangular wave. A pulse wave has a sound that is somewhat like the combined sounds of a flute and an oboe. It can also be used to create sharp rhythmic sounds more easily than the other basic waveforms.

Each of these basic waveforms has a reliable structure that exhibits strict amplitude relationships between the harmonics and their fundamental. They can also be combined to create richer, more textured sounds or used to modulate the amplitude or frequency of another sound, techniques that will be explored below.

One more basic waveform needs to be mentioned. It is called *white noise*, and it does not exhibit the structural symmetry of sine, triangle, sawtooth, or pulse waves. In the simplest sense, white noise is to those four basic waveforms what the color gray is to the primary colors: it is a combination of all of them, with no particular element dominating the mix. White noise is made when all the frequency and amplitude characteristics of a sound occur at random within the audio spectrum. It is a continuous dense hiss. It can be filtered and refined to sound like such things as the wind or the ocean, and is a rich source of background sound and texture for the composer of electronic music. Composer Allen Strange (b. 1943) defined white noise more precisely as containing all audible frequencies between 18 Hz and 22,000 Hz. A distilled form of white noise is called *pink noise*, which Strange defined as containing all frequencies between 18 Hz and 10,000 Hz. At the other end of the audio spectrum, noise restricted to the frequency ranges between 10,000 Hz and 22,000 Hz would be *blue noise*.[4]

Making Electronic Music: A Lexicon of Materials and Techniques

The science behind sound waves and the electrical generation of music brings with it a battery of tried-and-true techniques that have been explored since the earliest days of electronic music. As in the worlds of medicine, metallurgy, paleontology, or any other science you wish to name, those who tinker in electronic music have a language all their own. Sit for an afternoon with an electronic music mechanic—a composer who builds his or her own instruments—and you will be immersed in the jargon of filters, subharmonics, triggers, gates, and a bevy of other terms that seem to have no relationship to music whatsoever. Pioneers in the field were obsessed by their own creative forces to develop and master techniques for synthesizing sounds that had never existed before. The equipment they used was borrowed from the world of vacuum tubes and audio testing equipment. Acetate discs and tape recorders were their only means of recording the results. Loudspeakers were the stage from which the music emanated. Through their work and collaborations with audio engineers, a library of techniques for electronically creating and modifying sounds became a known and practiced craft.

The most common functions and components associated with music synthesis are described below. Though rooted in analog devices that predate the transistor radio, most of these principles of sound manipulation are still used today because they are, in the parlance of the computer industry, "platform-independent" techniques. Digital synthesizers, computers, and synthesizing software may have replaced the actual knobs and hardwired components of analog hardware with chips and virtual controls, but the processing techniques of current electronic music systems are modeled after the analog methods first developed thirty to fifty years ago.

Oscillators

An oscillator generates an audio frequency tone in the range that is audible to the human ear, from approximately 20 Hz to 20,000 Hz. Some oscillators may actually reach frequencies above and below hearing range, say, from 1 Hz to 22,000 Hz. These subsonic and supersonic ranges, although inaudible themselves, can still be used to modulate other waveforms.

Oscillators are included on sound chips in keyboard instruments. The sound card provided with personal computers also includes some basic sound-making capability, and more robust chip sets can be purchased as add-ons to expand the computer's ability in this regard.

Synthesizer oscillators usually provide a selectable range of waveforms for use by the composer, generally including the four basic types that we've already discussed: sine, triangle, sawtooth, and pulse. Synthesizers with preset instrumental voices use predetermined combinations of the available oscillators to produce different instrumental timbres.

Controllers

An electronic music instrument needs a way to physically sense the movements and gestures of the musician. A class of devices called controllers do just that. Many kinds of controllers have been created over the years to make an electronic music instrument playable by a composer or performer.

Direct manipulation of controls. The composer uses patch cords, dials, and switches to trigger sounds. The original synthesizers made by RCA, Moog, and Buchla worked in this way. They did not have piano-style keyboards. This is because the early synthesizers were not viewed as performance instruments. They were used with tape recorders in the context of the electronic music studio, and the music was put together piece by piece through tape editing. Synthesizers are still widely available today as rack-mounted components without keyboards. These "slave" sound modules can be triggered by a musician using MIDI signals from either a single controlling keyboard or through software "patches" on a personal computer.

Piano-style keyboard. Keyboards are the most common form of controller used on synthesizers. Today's keyboards are polyphonic–capable of playing more than one note at the same time–but this wasn't always the case. Commercially available voltage-controlled analog synthesizers available during the late '60s and early '70s could only play one note at a time: the highest one being played on the keyboard at any given moment. Each key represented a different amount of voltage. The early synthesizers were not performer-friendly. Even the simplest chord had to be created through multitrack recording.

In addition to the familiar black and white keys, electronic keyboards often have expression controls for embellishing the sound. Keyboards are usually touch-sensitive, so that the harder a person strikes the keys the louder the sound becomes. Another common feature of electronic keyboards is control wheels for bending a note or adding the wavering effect of tremolo.

Ribbons, plates, wands, and other controllers. Not all electronic music is meant to be played on a keyboard. Many innovative alternatives to controlling the sounds of a synthesizer have been developed over the years. Even the earliest solo instruments—the Theremin and Ondes

Martenot—were a dramatic departure from the norm. The Theremin is played by moving the hands in space within the proximity of two antennae, giving a performance a unique theatricality. The Ondes Martenot used the same sound-generating principles as the Theremin, but provided a sliding ring that was moved with one hand over a diagram of a keyboard, thus enabling the performer to hit the proper notes more easily than on the Theremin. Other unique methods have been developed over the years for the control of electronic musical instruments. One of Moog's original options was a ribbon controller. It was a monophonic device for the linear control of voltage and essentially served the same function as the keyboard but without the keys. It was used by sliding a finger up and down a slender metallic ribbon to cause changes in pitch. Like the Theremin and Ondes Martenot, the ribbon controller was especially suited to creating glissandi and wavering effects with unbroken chains of rising or falling notes.

Donald Buchla (b. 1937), the *other* inventor of the voltage-controlled synthesizer, has been devising unique controllers throughout his career. Like the Moog, the original Buchla synthesizer developed around 1965 did not have a keyboard. Instead, the player controlled the triggering of pitches and voltage-controlled actions by using a set of touch-sensitive pads. Buchla continued to noodle with touch-pad controllers and in 1990 manufactured the Thunder, a MIDI-compatible touch-pad controller for performers. In 1991, he introduced the Lightning, an optical MIDI controller that uses infrared beams to transmit control data from handheld wands to any MIDI-compatible synthesizer equipped with a receiver. The speed and position of the wands can be used to trigger a variety of MIDI parameters, including pitch but also the panning of sound and volume level. In 2000, a Lightning II model was introduced, with the added bonus of a thirty-two-voice synthesizer, making it a complete, ready-to-play instrument. Yet another Buchla invention, the Marimba Lumina, translates the keys, program switches, and editing controls of a normal synthesizer into a marimba-like surface with controller strips instead of keys. The strips are played by four different programmable mallets. One can use the Marimba Lumina in place of a keyboard to control MIDI-compatible synthesizers.

Sequencers. The term "sequencer" was associated with voltage-controlled analog synthesizers. It referred to a module that could be programmed to store a pattern of DC voltages used to control a voltage-controlled oscillator. A sequencer could receive its control-voltage pattern from a keyboard, ribbon controller, or other voltage-control source. It allowed a series of notes to be programmed and played back at different speeds or with different synthesizer voicings. The Buchla synthesizer was the first to incorporate a sequencer, which soon became a common accessory for any voltage-controlled synthesizer. Before the introduction of MIDI in 1983, sequencers were the most popular method of storing strings and patterns of notes. They were typically used to provide steady rhythms and harmonic lines that could be repeated while other sounds were played freely at the same time. Sequencer music became synonymous with the steady, trancelike rhythms that characterized the music of such artists as Tangerine Dream, Kraftwerk, Isao Tomita (b. 1932), and Klaus Schulze (b. 1947). Although the term "sequencing" is often used today in reference to software that can record MIDI sequences of notes, the analog sequencer hardware that was once widely used has long since passed from the scene.

MIDI. By 1984, a significant step toward a standardized industry approach to digital synthesizer interface was reached with the introduction of MIDI—the Musical Instrument Digital Interface. MIDI permits instruments made by different companies to be linked electronically for control purposes during performance. It allows a single performer using a single keyboard or other controller (e.g., software) to play more than one instrument at a time, regardless of the make and manufacturer of the gear. The control signals from the single keyboard are transmitted through MIDI interface communications to the other synthesizers that are linked to it, thus permitting the orchestration of music using a variety of MIDI-compatible instruments.

MIDI was a natural outgrowth of the microcomputer and affordably married the electronic musical instrument to the computer. It remains the standard interface employed by all commercial makers of music technology.

The original specification for MIDI was the result of a collaboration between competitors in the then-explosive market for commercial synthesizers. Roland, Yamaha, Korg, Kawai, and Sequential Circuits all contributed to version 1.0 of the spec, which was completed in August 1983.[5] It was not a perfect standard and was mostly championed by those who were interested in the commercial application of electronic musical instruments for the making of popular music. This oriented MIDI toward keyboard music, not the cup of tea preferred by many composers in the field. Still, it succeeded in providing genuine compatibility among different instruments and the computer and led to explosive growth in the making of software and hardware for the music industry. It was the evolutionary leap that led to widespread growth in the music technology industry.

What does MIDI do? It communicates the values of notes played on the keyboard, including the pitch, amplitude, and duration. This should not be confused with *recording* the sounds played by the keyboard; MIDI "records" only a sequence of note values. The timbre, or quality of the sound, is the provenance of the synthesizer that receives the MIDI sequence. A sequence of MIDI note values is independent of the sound or voice of the instrument playing the notes. The same sequence of note values can be played on different instruments using different voices.

MIDI: Musical Conformity or Just Another Creative Tool?

By 1984, the makers of commercial synthesizers and PCs were feeling pressure from consumers to provide universal connectivity of their gear. No industry-wide standard existed at the time for allowing a PC to control or communicate with a synthesizer. When a manufacturer chose to connect a computer with a synthesizer, it did so using expensive and quickly outdated proprietary methods that were unique to its own products. The time had come for the industry to eliminate this problem.

The answer was a protocol called the Musical Instrument Digital Interface, otherwise known as MIDI. Introduced in 1984, it was the result of many months of behind-the-scenes cooperation and squabbling by several leading electronic instrument manufacturers, including Roland, Oberheim, Sequential Circuits, Yamaha, Korg, and Kawai.

The MIDI control signal can communicate several parameters about musical notes that are independent of the instrument on which they are played. These parameters include the pitch value, its amplitude (how hard a note is played), the effects of using a pitch-bend wheel, modulation wheel, and volume pedal, and how hard a key is pressed while a note is being sustained.

The MIDI interface was designed with two basic performance applications in mind:

- MIDI can connect standalone electronic music instruments and permit one instrument to control the sounds being made on several others. This can be done without a separate computer. The instruments may or may not have keyboards, although in a typical multi-instrumental setup there is at least one keyboard that triggers all of the activity.
- MIDI can connect standalone electronic music instruments with a PC. In this configuration, the computer is used to trigger sounds and patterns on the connected instruments. Many multiple MIDI channels may be operated simultaneously in this way.

As with any industry standard, the creation of the MIDI protocol was not completed without some compromises. The primary limitation of MIDI is that it was conceived with the production of keyboard music in mind. This was rightfully viewed as providing the most widespread commercial application of the standard, but it potentially left in the lurch many composers who had ideas unrelated to keyboard music. Over the years, however, MIDI has proved to be eminently adaptable by engineers and composers alike, so that today its limitations are often overcome in many creative ways. Not long after the introduction of MIDI, the same protocols used to generate control signals between keyboard synthesizers were being adopted for a wide variety of other musical applications. Wind instruments, drum machines, and effects boxes all became MIDI-compatible. David Rockeby in Toronto created a way to translate images from a video camera into MIDI signals. His Very Nervous System was used in 1991 to interpret and translate the images of a dancer into musical accompaniment. Donald Buchla has devoted his most recent years to the development of new controllers that can take advantage of MIDI. Results of his work include the Lightning, a wand controller that translates the physical movement of a handheld wand in space to MIDI input signals.

Since 1978, Michel Waisvisz, the director of STEIM (Studio for Electro-Instrumental Music) in Amsterdam has dedicated himself to the creation of gestural controllers for live electronic music performance. He was on the crest of the MIDI wave in 1984. He does not record his own music anymore, instead favoring "the reality of the concert hall: direct, in contact with the audience, tangible, sensitive, sweaty and excitingly real."[6] One of his earliest electromechancial controllers was called Hands, first used in 1984. It consists of a pair of metal plates shaped so that one can be worn comfortably on each hand. The Hands contain touch-sensitive keys that can be played by the fingertips as well as sensors that respond to tilt and the changing distance between the two Hands. They send control signals to sound modules to generate sound in real time.[7]

One might think that an iconoclast like Robert Ashley would have resisted the rigor imposed by MIDI, yet he embraced it almost immediately, because it freed him from having to enlist an orchestra of acoustic instruments for certain kinds of compositions that he was contemplating. One of these was *Superior Seven* (1986). He explains it this way:

> When *Superior Seven* was composed, the MIDI system was a barely workable technology, and I must say that because I did not own a computer then and because I was not much interested in "computer music," the idea of a composition that is so appropriate to MIDI could not have occurred to me. But *Superior Seven* is very appropriate to realization in MIDI, and MIDI—not an orchestra of acoustical instruments—is the technology of this recording.[8]

The piano part of the work played cues for other instruments. The other instruments were intended to play the same notes in the same register in precise synchronization with the piano cues: "Thus, the cue lines serve the same function as a sequence of note-instructions from the computer, and the cue lines 'conduct' the entrances of all the other instruments in the orchestra."[9] If he had used a live orchestra to perform the work, Ashley likened the role of the conductor to that of "the mixer at a recording console." The use of MIDI provided an ideal solution for him.

Additive and Subtractive Synthesis

Synthesis is the ability to use the fundamental building blocks of sound to construct new sounds. The earliest electronic music composers had no synthesizers at their disposal. Armed only with waveform oscillators, filters, and tape recorders, they learned how to combine and modify existing sounds to make new ones from the simplest component parts.

The simplest form of sound synthesis is the combination of two or more sine waves into a more complex waveform. This process is called *additive synthesis* and can be used to create diverse sounds by building up layers of many individual sounds. Each wave source can be treated and varied independently. In the old days, this was done by combining the sounds of several audio oscillators to produce a new result. For example, a triangle wave could be constructed by using many individual sine waves. The base or fundamental sine wave would be the loudest, and additional sine waves would be added to build the overtone structure characteristic of a triangle wave. It was a tedious way to work and required much trial and error. The result was difficult to reproduce without precise details of the settings for each of the oscillators.

Just as waveforms can be constructed by the addition of one sound to another, they can also be altered through the systematic elimination of certain parts of the sound, such as overtones or the fundamental frequency. This practice is commonly achieved through sound filtering and is called *subtractive synthesis*.

A familiar example of a filter is the sound "equalizer" available on home stereo systems. This device permits the listener to filter out various bands of frequency, usually for the purpose of eliminating noise in the high ranges and adjusting bass and treble to more closely match the acoustic requirements of a given space. In a more novel way, equalizers are sometimes used to filter out the voice of a performer on a record in order to leave only the instruments playing.

As a synthesized sound passes through a filter, it allows some frequencies to pass and cuts off others. Filters designed for electronic music come with several specific purposes in mind.

Band-pass filter. Allows only those sounds *between* specified high- and low-frequency cutoff points to be heard. It removes the high and low frequencies from a tone at the same time.

Band-reject filter. Allows only those sounds *above* or *below* specified high- and low-frequency cutoff points to be heard. It removes the midrange frequencies from a tone.

Low-pass filter. Allows only frequencies *below* a specified cutoff point to be passed. It removes the high frequencies from a tone.

High-pass filter. Allows only frequencies *above* a specified cutoff point to be passed. It removes the low frequencies from a tone.

Filters may be part of a synthesizer console, a software component for processing sounds, or a standalone device used like an effects box between the instrument and the amplifier.

Envelope Shaping

The envelope of a sound is the way the sound begins, continues, and then ends. It is the result of amplitude modulation. A note played on the piano, for example, begins with a sharp attack but may be made to end quickly or slowly, depending on whether the sustain pedal of the instrument is depressed. Notes played on wind instruments, such as the saxophone or flute, typically begin and end sharply. Electronic musical instruments offer the unique ability to vary and control the envelope characteristics of a sound. This technique can be used to change the attack characteristics of all sounds activated by the keyboard. Rather than having abrupt, instantaneous attacks, like the notes played on a piano, the sounds can be made to have slowly rising attacks of increasing volume.

Amplitude Modulation (AM)

Amplitude modulation (AM) is the use of a control voltage to alter (modulate) the loudness of another signal. The sound that is being modulated is called the carrier signal. When a subaudio signal is used to modulate a given sound wave, the result is a slow, undulating effect called *tremolo* in which the volume of the sound becomes alternately louder and softer but without changing the pitch. The loudness rises and falls around a central amplitude.

All types of waveforms can be used as control signals. Using a sine wave to modulate the carrier will cause the loudness to rise and fall very gradually. A triangle wave will effect a gradual rise in loudness that sharply turns down and gradually falls, only to switch directions again very sharply. The use of a pulse wave as an amplitude-modulating signal eliminates the various gradients between loud and soft, and causes the carrier to switch instantly between the two extremes.

When the control signal is a waveform in the audio range, the changes in loudness become much more difficult to perceive because of their rapidity, and the resultant effect is the creation of audible *sidebands* of the carrier signal. Sidebands are the partials or harmonics that make up part of a total sound but do not dominate it. They add tone color or body to the sound. Sidebands are mathematically related to the carrier: the upper sidebands are equal to the sum of the carrier and control frequencies, while the lower sidebands are equal to the difference between them. When sidebands become audible, the carrier signal still remains the dominant signal.

Frequency Modulation (FM)

Frequency modulation (FM) is the use of a control voltage to alter the frequency (pitch) of the sound. A subaudio control voltage will produce a *vibrato* effect, which is an undulation of pitch around the central carrier tone. As in amplitude modulation, when the control voltage is in the audible frequency range, the resultant signal contains sidebands of the carrier wave. The complexity and harmonics of FM sidebands are much more intricate and rich than those produced by AM. Unlike AM, FM sidebands may actually dominate the carrier tone.

Ring Modulation

Ring modulation is a form of amplitude modulation in which special circuitry suppresses the carrier signal and reproduces only the sidebands. Two additional frequencies are created in place of the original carrier signal. One is equal to the sum of the two input frequencies, and the other is equal to the difference between them. If the input signal has many harmonics, such as a guitar or the human voice, the resulting output signal is complex and rich, a kind of ghost of the original sound. The analog ring modulator still being made by Robert Moog (b. 1934) has a second input signal in the form of an oscillator. This can be adjusted to narrow or widen the distance between the two frequencies generated by the effect.

Other Electronic Music Techniques and Effects

Amplification of sounds. A microphone and amplifier can be used to pick up any sound and feed it into a synthesizer or computer for modification. This puts the entire universe of sounds at the disposal of the composer. A microphone converts sound into analog electrical signals. The analog signal can be modified for input to a computer using an analog-to-digital converter.

Two kinds of microphones or pickups have been commonly used in the production of electronic music:

> **Conventional "air" microphones.** These are the most familiar type of microphone and are designed to react to pressure waves in the air. Condenser or electrostatic microphones are the preferred kinds for making accurate recordings of sounds such as instruments, voices, and ambient noise. These kinds of microphones can generally detect sounds in the full frequency response range of human hearing, say, from less than 100 Hz to about 20,000 Hz.

> **Contact microphones:** These microphones are designed to pickup vibrations while in direct contact with a vibrating or resonating surface. They are quite limited in their frequency response, only sensing a narrow band of frequencies of no more than a few thousand hertz, usually at the lower end of the scale. Even so, contact microphones are a familiar staple of electroacoustic music because of their ability to amplify quiet, undetectable sounds. They can be inexpensively constructed using a few dollars' worth of parts from Radio Shack.

Other kinds of pickups that can be used to detect sound waves include magnetic pickups found on guitars, and the humble phonograph cartridge. Around 1960, John Cage and David Tudor discovered that they could get some startling results by using a phono cartridge as a kind of contact microphone. The cartridge is designed to pickup the vibrations present in the groove of a vinyl audio recording. It does this by way of a needle or stylus that runs in the groove of the record. The vibrations are then converted into electrical signals that are amplified. Cage and Tudor made their new sounds by detaching the cartridge from its tonearm, replacing the phonograph needle with objects such as toothpicks, Slinkys, and straight-pins, and then amplifying the results of physical contact between the surrogate "needle" and other objects.

Feedback. Composer Robert Ashley calls feedback "the only sound that is intrinsic to electronic music."[10] Not only is it a natural effect that is available whenever a microphone or audio pickup is used, but it also introduces the use of sustained sounds, which is one of electronic music's inherent attributes. While it is certainly one of the most familiar and easily obtainable effects when using a microphone or amplified instrument, it is one of the most delicate and difficult to control.

Feedback is a wonderfully rich and expressive voice when incorporated into music. Ashley himself is famous for his piece *The Wolfman* (1964), a very early manipulation of feedback as an intentional part of the music. In this piece, the level of amplification is set very high, at the point of feedback for the given audio space. The performer delivers a set of vocal patterns while keeping his mouth in very close proximity to the microphone. Ashley described the effect:

> In *The Wolfman* the feedback is tuned for whatever place you're performing in. Then into that feedback are put different kinds of modulating materials on tape. That modulated feedback product is passing through the sole microphone in the space, the singer's microphone. That means that by just putting your mouth up against the microphone, and by doing very simple vocalisms, you can affect that whole feedback system in a very slow, modulation filtering sense. That's the principle of the piece. The feedback is a loop and the tape sound is being broadcast into that loop. The bottleneck in that loop is the microphone so that by treating the resonant cavity right in front of the microphone you actually create a model of the room in the size of the vocal cavity. It's a very simple principle. The room just keeps moving around and changing shape because of the way you shape your mouth. The act of doing it in the presence of that sound–the feedback–is so overpowering to the listener that no one ever understands how the sound is made.[11]

Steve Reich (b. 1936) arrived at his work called *Pendulum Music* (1968) by devising a way to manipulate the raw power of acoustic feedback using the mechanics of a swinging object. In this work, one or more loudspeakers were placed on their backs, aimed at the ceiling. Microphones were the source of the input signal. The amplitude was turned up to the point where feedback would occur if the microphones were brought within proximity of the front of a loudspeaker. The microphones, suspended from the ceiling on long cables like pendulums, were then swung so that they would pass just over the loudspeakers. As a microphone crossed the space above a loudspeaker it would create a whooping feedback sound. As the swing of the microphones eventually decayed, they came to rest directly over the loudspeakers, causing uninterrupted feedback until the amplifier was shut off.

Reich, whose highly determinist compositions stand in stark con-

trast to Cage's work, was amused by the combination of process and chaos that *Pendulum Music* represented:

> Over a period of ten minutes, which was a little too long for my taste, and as the pendulums come to rest, you entered a pulsing drone. Once it hit the drone, I would pull the plug on the machine and the whole thing ended. It's the ultimate process piece. It's me making my peace with Cage. It's audible sculpture. If it's done right, it's kind of funny.[22]

What began as a straightforward compositional process ended with the cacophony of an opposing process: uncontrolled electronic feedback.

New Yorker David Lee Myers (b. 1949) has been creating electronic music using *only* feedback for over twenty years. His is not feedback of the acoustic variety, however, for the sound does not result from the interference of a highly amplified signal in the proximity of a loudspeaker. He feeds electronic circuits back onto themselves to create interference noise that he can then mix, filter, and shape using audio processors:

> The idea is that an effects device is fed some of its own output—much like a squealing speaker which accidentally feeds the microphone supplying its input—and electrons begin to flow as they wish. The trick is to shape this flow, select the feedback paths which create an aesthetically pleasing, or whatever direction and shape. What is required is several devices whose business it is to bend sound into various shapes, and a routing scheme which allows them to speak to each other and to themselves.[13]

Using a variety of specialized "feedback workstations" that he has constructed over the years, Myers creates a music with no human origins—no keyboards signaling pitches, no dials setting frequencies, no musical interfaces whatsoever. The result is a music of the ether that he shapes as the elements allow. His sonic washes sometimes result in soothing drones. Other times they pulse with the beat of interfering electrical signals.

Japanese composer Toshimaru Nakamura (b. 1962) has recently borrowed a page from Myers' book. He wires a mixing panel so that its output line is plugged into its input line to create minimal sonic pictures resulting from his "no-input mixing." Whereas Myers explores the vast peaks and valleys that can be generated by internalized electronic feedback, Nakamura is intent on reducing the experience to a wire-frame representation of sound.

Reverberation. Unlike echo, reverberation does not involve the periodic repetition of a given sound. "Reverb" adds resonance and depth to a sound, much as singing in the bathroom or shouting in a large auditorium does. In a sense, reverb is really a sound with many echoes that are spaced so closely that they do not become distinct or separate from the original sound.

Reverb was first achieved electronically by running a sound through a metal spring before amplifying it. This created additional vibrations of the sound and the sound shadows associated with reverb. The amount of spring reverb could be controlled by adjusting the tension of the spring and the amount of amplification of the signal passing through it. Like echo effects, reverb is now created using digital circuits that model analog spring reverb but also provide greater control and precision in setting the level of reverberation desired.

Recording and sampling. The tape recorder was the original "sampler," allowing its user to manipulate recorded sounds and make them a part of an abstract musical composition. The entire body of tape music collectively known as musique concrète was based on the concept of sampling. It depended on removing sounds from their familiar surroundings and recontextualizing them as a form of musical expression. Sampling is done today using digital recorders, software editors, and specialized sampling keyboard instruments.

Chapter 3

MUSICAL PRECEDENTS TO ELECTRONIC MUSIC: ORIGINS OF THE AVANT-GARDE

Electronic music is an outgrowth of larger trends in twentieth-century music and culture. A new avant-garde was developing that rejected old rules of melody, harmony, rhythm, and composition. Electronic musical instruments were a liberating force behind new musical style. To understand the development of electronic music, we have to briefly review the early history of twentieth-century music.

The expression "avant-garde" was originally a French military term meaning "vanguard," as in the first wave of soldiers mounting an attack. These were the soldiers most likely to be killed while leading an assault on a well-fortified enemy compound. The term was borrowed by Parisian artists of the late nineteenth-century, no doubt because they too felt the somewhat daunting futility of putting their careers on the line while battling the more conservative tastes of the typical patron of the arts.

Historically, the avant-garde emerged during a time of great change in society. The industrial revolution spread new technology at an unprecedented rate. Electricity illuminated once-darkened nights. Telephony dramatically modified our concepts of time and space by allowing two people to communicate at the same time without being in the same place. The automobile allowed people to more fully explore the world beyond their neighborhood. It was a time of great hope but also of great struggle. The industrial revolution increased the stratification of society by expanding the ranks of the rich and the poor alike. It also fed the world's military powers with new and improved weapons of war, leading to conflict after conflict and eventually to World Wars I and II.

As has always been the case, artists are apt to reflect changes in society by making changes in their art. Beginning in the 1880s, composers responded with a revolution of their own.

Alternate Pitch Systems, New Scales, and Atonality

As the nineteenth-century drew to a close, some composers were beginning to question the limitations of the equal-temperament scale, the tuning system that had evolved in the seventeenth-century as the de facto standard for use in orchestral music. The adherence of this scale to twelve tones of equal intervals allowed for smooth transitions from key to key and was easily adapted to the tonal ranges of the orchestral instruments that had evolved by that time. The piano itself was a reply from the industrial age to the twelve-tone, equal-temperament scale: a musical machine with a fixed set of musical intervals that would stay in tune for a long time.

The equal-temperament scale, of course, is not universally found in all world music. Some systems use whole-tone instead of half-tone scales; others use scales with more or fewer tones and equal or unequal steps between them. By the turn of the century, Western composers became increasingly aware of alternative scales and the possibility that an octave might be divided into more than twelve equal steps. Any scale with more than twelve steps is known as a *microtonal* scale.

One of the first modern composers to experiment with different scales was Erik Satie (1866–1925). In 1887, after having dreamed away several years at the Paris Conservatoire, the young Parisian wrote his *Gymnopédies* (1988) and *Sarabandes* (1887) for piano. He had become bored with the contrivance of major-minor tonality as found in Germanic symphonies and operas, and was no more enamored of the self-conscious approach of "impressionist" music—then still a young movement. He was later to comment on his experience at the Paris Conservatoire, "My harmony professor thought I had a gift for the piano, while my piano professor considered that I might be talented as a composer." Satie set forth to create a new music of lucid clarity, stripped of ornamentation and "sauce," as he called it. The result was a blow for simplicity straight from the heart of this most original of composers.

Satie first applied medieval scales and the modes of Gregorian chant to his music in the *Gymnopédies* and *Sarabandes*. These haunting and unforgettable pieces employed delicate melodies in conjunction with floating harmonic blocks and unresolved chords to suspend the sound, with a kind of mystical aura. Some of the scores for Satie's early piano works omitted bar lines as well as time and key signatures.

Satie was eccentric in almost every respect. He notated his scores with humorous and banal instructions to test the performer's wit and

engage him or her psychologically in the performance of his works. Written above the staff instead of instructions such as "Slowly" or "Moderately," one was more likely to find a performance indicator such as "A bit rococo but slow," "Dance inwardly," "Do not cough," "Cloisterly," "With tears in your fingers," "Like a nightingale with a toothache," or dozens of other instructions.

Satie's acerbic wit, indifference to public acknowledgment, and penchant for unusual titles (such as *Veritable Flabby Preludes, Chapters Turned Every Which Way,* and *Old Sequins and Old Carcasses*) gave his reputation an aura of self-imposed ridiculousness. Yet the experiments he undertook to free French music from the European traditions were the force underlying much of the impressionist movement. Debussy, for instance, went on to employ the pentatonic and other medieval scales and to a large extent receives credit for developing these techniques, which were in fact first attempted by Satie.

Debussy became *the* pivotal figure of modern music in France. In 1889 he attended the Paris Exposition, which marked the one-hundredth anniversary of the French Revolution. There he heard Balinese gamelan music for the first time. His exposure to this led him to experiment with the whole-tone scale, which is suggestive of Far Eastern modes. Debussy was brimming over with creative enthusiasm and seized every experience, every influence, as a means for mobilizing his own ideas. He was a marvelous assimilator of concepts, an archetype of the modern composer in a world that has fewer and fewer ethnic, and sonic, borders.

Debussy first met Satie in 1890, when Satie was performing as pianist at Le Chat Noir, a well-known cabaret in Montmartre. Satie, twenty-four, and Debussy, twenty-eight, became fast friends. Both were disillusioned with the current condition of music, and as they watched their peers wallowing in the mire of Wagner, each laid down plans to change the state of the art. By this time, both men had experimented with unusual tonal scales, suffered through an academic environment in which their ideas were met with indignation, and become charter members of the avant-garde social life of Paris. It was probably during one of their discussions at a French club that Satie uttered his famous line "We ought to have our own music—if possible, without sauerkraut!"

Satie shared some thoughts with Debussy on a lyric opera he was considering. As the story goes, Debussy was so influenced by this conversation that he went on to compose his only completed opera, *Pelléas et Mélisande*, which took him ten years to write. In the meantime, Satie continued to sculpt his whimsical, crystalline piano works with such titles as *Pièces froides* (Cold Pieces, 1897) and *Trois morceaux en forme de poire* (Three Pieces in the Form of a Pear, 1903).

Satie and Debussy perfected several distinct experimental approaches to music, including: the use of organum, in which two or more melodies are written in parallel so that they rise and fall in equal steps simultaneously; the application of the whole-tone scale and other scales consisting only of primary intervals and lacking major and minor steps like the half steps of the chromatic scale, as found on the piano; and the use of repetitive chords in a steady rhythmic pattern to achieve a suspension of motion and tension. Perhaps the foremost preoccupation of both composers was their effort to free melody from its traditional underpinning of keys and chords, allowing it to move and develop independently of any presupposed and melodramatic superstructures. This gave much of their music its detached, disembodied serenity.

Vexations (1893) was Satie's most enigmatic and abstract work. Comprising a score of only one page, it consists of 180 notes to be played on the piano with the following instruction written at the top: "To play this motif 840 times in succession, it would be advisable to prepare oneself beforehand, in the deepest silence, by serious immobilities." This previously unknown work was brought to the attention of John Cage in 1949, and in 1963 Cage produced its first performance using a relay team of ten pianists. The performance took more than eighteen hours. Had the term "minimalism" been in vogue at the time, *Vexations* would no doubt have been branded as its granddaddy. Cage summed up the performance in this way:

> The experience over the 18 hours and 40 minutes of those repetitions was very different from the thought of them or the realization that they were going to happen. For them to actually happen, to actually live through it, was a different thing. What happened was that we were very tired, naturally, after that length of time and I drove back to the country. . . . I slept an unusually long period of time, and when I woke up, I felt different than I had ever felt before. And furthermore the environment that I looked out upon looked unfamiliar even though I had been living there. In other words, I had changed and the world had changed. . . . It wasn't an experience I alone had, but other people who had been in it wrote to me or called me up and said that they had had the same experience.[1]

The score of *Vexations* is perplexing and defies a performer's normal musical instincts. It is not easy to play even once, let alone 840 times. It becomes an exercise in deep concentration, a transfixing experience that reprograms the consciousness of those who perform and listen to it. It is perhaps the first calculated example of a western composition made to create a new state of listening. In this way, it has an overtly spiritual function as music. Its performance has a reality-altering effect that is more like that of an Indian raga or Balinese monkey-chant than a recital of European music.

During the same period that Satie and Debussy began using whole-tone scales, a number of other composers and theoreticians began to suggest even more elaborate approaches. Microtonal scales employ intervals that are smaller than the traditional half tones of the chromatic scale. A composer may devise any division of the octave that is desired. Early proponents including Shohe Tanaka and Carl Fitz created microtonal scales having from 20 to 104 notes per octave. Unfortunately, no instruments existed at the time for playing such music. These ideas clearly anticipated the need for new kinds of instruments, which was never satisfactorily addressed until the development of electronic music synthesizers that could be tuned in variable scales.

In 1888 a fourteen-year-old American named Charles Edward Ives (1874–1954) wrote his first song, *Majority*. In the piano accompaniment, he used a tone cluster, which required the simultaneous playing of adjacent keys on the piano—a rebellious act for a beginning composer. This is probably the first documented use of a tone cluster in a score. Ives went on to employ the device in many later pieces. True to form, he remained a musical rebel throughout his career, developing into one of America's most original and prolific modern composers. He added several new techniques to the lexicon of composition, including polytonality (the use of different keys simultaneously), polyrhythms (the simultaneous use of different rhythms), and polymeters (layers of differing rhythms and rapidly changing meters). He also explored microtonal music, mostly through his piano work for quarter tones. The resourceful Ives once tuned two pianos a quarter tone apart so that he could compose and play his *Three Quartertone Piano Pieces* (1923–24).

Following the early work of Satie, Debussy, and Ives, the exploration of alternatives to the standard chromatic tonal scale was championed by many composers. They included Ferruccio Busoni (1866–1924), Béla Bartók (1881–1945), Arnold Schoenberg, and Anton Webern (1883–1945). In 1907, Busoni, a well-known Italian-German pianist, composer, theoretician, and teacher, read about the Telharmonium of Thaddeus Cahill (1867–1934) in *McClure's* magazine. He was inspired by the possibilities of using such an instrument to develop new tonal scales and was compelled to write about it in his famous manifesto *Entwurf einer neuen Ästhetik der Tonkunst* (Sketch of a New Aesthetic of Music):

> Dr. Thaddeus Cahill . . . has constructed a comprehensive apparatus which makes it possible to transform an electric current into a fixed and mathematically exact number of vibrations. As pitch depends on the num-

ber of vibrations, and the apparatus may be "set" on any number desired, the infinite gradation of the octave may be accomplished by merely moving a lever corresponding to the pointer of a quadrant.

Busoni came the closest to recognizing the value of the Telharmonium as a precursor of an experimental age of music. It took nearly sixty years for this vision of electronically generated microtonal scales to become truly practical with the development of the analog synthesizer.

In 1906 the Hungarian composer Béla Bartók began to incorporate elements of his country's native folk music into his compositions. This folk music impressed him with its use of old musical modes, lack of major and minor keys, and employment of pentatonic scales. His *Twenty Hungarian Folksongs* (1906) was an early work to exhibit this influence. Bartók became noted for using polymodality (combining different modes), polytonality (combining major and minor keys), percussive dissonance (anticipating Stravinsky), droning bass lines, repeated notes, repetitive rhythmic structures, and tonal dissonance.

Arnold Schoenberg composed his last piece of music to use a major or minor key signature, the *String Quartet No. 2 in F-sharp Minor*, in 1907, and turned his attention to creating what he called *twelve-tone music*. By the '20s, he had refined his technique so that it focused on a basic characteristic of the equal-temperament scale that had previously been avoided. In his system, the smallest atomic unit of the scale was not the chord, as had been previously practiced, but an individual note. Thus he discarded the time-honored rules governing tonal harmony and key relationships. He and his followers Alban Berg (1885–1935) and Anton Webern began to compose music based on the relationships of the notes to one another, regardless of key. Notes were free to be themselves without respect to traditional harmony. Schoenberg did not want to encourage total chaos, so he made up some rules. They could be applied to any adjacent set of twelve notes (black and white keys) you can play on the piano:

- The twelve notes must be arranged in a definite order (the tone "row").
- Each composition is created around its own tone row.
- The twelve tones can be used in a melody in any order, provided that no tones are repeated before any others are used.
- Each tone is given equal importance and is not reliant on a tonic (the keynote of a melody; in the key of C, the C note is the tonic).
- The tone row may be inverted or reversed.[2]

Music composed using this twelve-tone system is called *atonal* music because it lacks a tonal center or key.

With its emphasis on the tone row, this music avoided the use of familiar chord and melody structures, and employed a highly organized, often mathematical approach to building a piece of music from sequences of notes.

Webern elevated twelve-tone technique to extremely high altitudes, where the air is thin and time seems to slow. He extended Schoenberg's principles by applying them to tone color—the combination of instruments that he would allow to play at the same time. In his *Symphony* (1928) for chamber orchestra, the theme is brief and consists of seemingly isolated tones that bear little relationship to one another. Schoenberg's non-repeat rule is applied to tone color: each instrument is allowed to play only one note at a time and does not play another note until all the other instruments have been heard from in turn.

Webern's music is austere and threadbare, a clothesline without the clothes. He exploited the most radical portions of Schoenberg's doctrine, and suppressed all repetition in his work, feeling that this led to a continually renewable source of creativity. There is a nascent tendency in twelve-tone music toward time compression that Webern took to extremes. His works are shorter than short. The *longest* of his *Five Pieces for Orchestra* (1911–13) is only a minute. His life's output consists of only thirty-one works, and it only requires about three hours to play them back-to-back. "This is not much to show for a creative activity that extended over thirty-five years," remarks music historian Joseph Machlis, "but the music is so carefully calculated that it impresses one as having been written at the rate of a few notes a day."[3]

Webern moved toward the complete control of all tonal elements of a work, applying strict rules to the designation of pitch, timbre, and rhythm. Those that followed him—most notably Pierre Boulez (b. 1925) and Karlheinz Stockhausen—extended his ideas even further by seeking the total "serialization" of a piece of music, applying his technique not only to pitches, timbres, and rhythms, but to dynamics, densities, and amplitude as well.

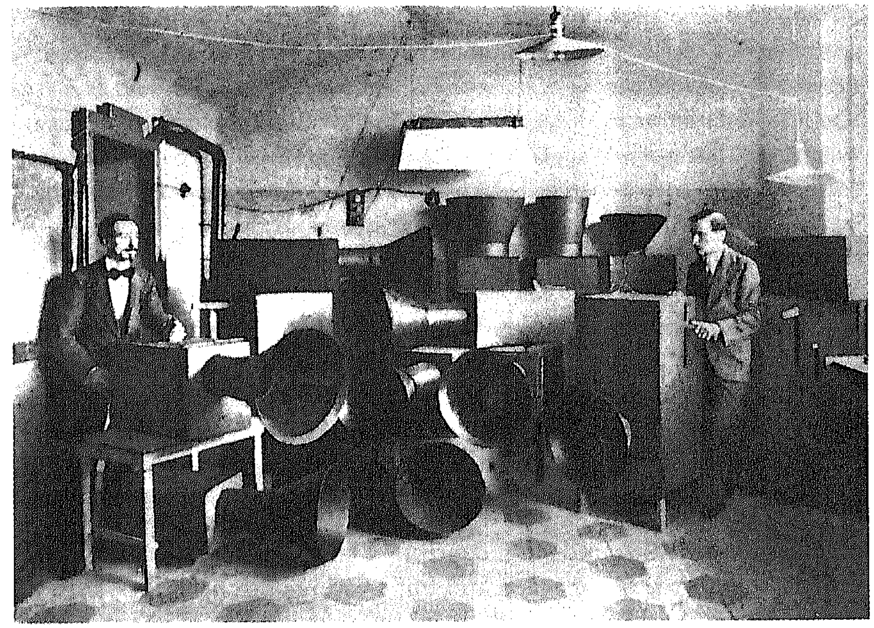
Webern's life was cut short by a tragic case of mistaken identity. After surviving the Nazi regime in Germany, he was accidentally shot dead by an Allied soldier in 1945, five months after the end of the war, while violating a curfew to smoke a cigarette.

The "Art of Noise" In Music

By 1910, music patrons were politely humoring the eccentric approaches to tonality that could be heard in the works of Debussy, Ives, Schoenberg, Satie, and others. This set the stage for the next onslaught, for which they were hardly ready: the use of noise as an element in music. This movement began, appropriately, with the piano. In his *Allegro barbaro* (1911), Bartók suddenly began to pound loud, dissonant "chords" on the keyboard. Even more alarming, though, were the antics of a young composition student at the University of California named Henry Cowell. In 1912, Cowell took Ives's tone cluster to the next level, making it the centerpiece of many compositions. Whereas Ives had mostly restricted his clusters to two or three simultaneous notes, Cowell banged on the keyboard with his forearm, the flat of his hand, or a length of wood in order to depress an entire range of adjacent keys at the same time. Going even further, he plucked and struck the strings on the inside of the piano. His techniques were so well developed that he published a book called *New Musical Resources* in 1930 (written in 1918 when he was only twenty-one) to document his efforts. Cowell was one of the most durable members of the American avant-garde and gained notoriety for his performances during the 1920s and 1930s.

Even more startling was the Futurist movement, which sprang up in Italy in 1909. It was conceived and organized by poet Emilio Filippo Tommaso Marinetti (1876–1944), and while its primary focus was in the visual arts, some of its members became interested in new musical ideas. In 1911, the composer Francesco Balilla Pratella (1880–1955) published a manifesto, *Futurist Music*. In this work, he expressed sentiments not unlike those being put forth in Germany, France, and the United States. He was interested in expanding the range of harmonic music through the use of semitones and agreed with the use of a "chromatic atonal mode," as previously introduced by Schoenberg. He called this the "enharmonic mode," and although he claimed this development as "a magnificent conquest by Futurism," his formula does not seem to be vastly different from theories being considered elsewhere at that time. In addition, Pratella hoped to "crush the domination of dance rhythm" in order to create a freer approach to tempo, and to take charge of polyphony as a way of "fusing harmony and counterpoint."

In 1913, Pratella introduced his music at a concert at the Teatro Costanzi in Rome. He conducted his piece called *Musica Futurista* for orchestra, much to the delight of his Futurist compatriots. One painter, Luigi Russolo (1885–1947), was so inspired that he quickly wrote his own manifesto, *The Art of Noise* (1913). Russolo's ideas were more extreme than Pratella's. Pratella's objective was to develop new pitch and rhythm systems to expand the potential of existing instruments. Russolo envisioned entirely new ways of making music through the use of noise. He not only put his ideas on paper but immediately abandoned painting and devoted himself full-time to the design and invention of new mechanical noisemakers to produce his music.



Luigi Russolo and his assistant Ugo Piatti with Intonarumori, 1914. Used with permission of the Philadelphia Museum of Art, the Harry Lewis Winston Collection.

Russolo's manifesto is an impressive document and certainly an influential precursor of modern experimental music. Had the tape recorder been in existence during his time, Russolo probably would have invented his own form of musique concrète. Here are some representative statements translated from *The Art of Noise*:

> Ancient life was all silence. In the nineteenth-century, with the invention of the machine, Noise was born. Today, Noise triumphs and reigns supreme over the sensibility of men.
>
> At first the art of music sought purity, limpidity and sweetness of sound. Then different sounds were amalgamated, care being taken, however, to caress the ear with gentle harmonies. Today, music, as it becomes continually more complicated, strives to amalgamate the most dissonant, strange, and harsh sounds. In this way we come ever closer to *noise-sound*.
>
> The musical evolution is paralleled by the multiplication of machines, which collaborate with man on every front. Not only in the roaring atmosphere of major cities, but in the country, too, which until yesterday was totally silent, the machine today has created such a variety and rivalry of noises that pure sound, in its exiguity and monotony, no longer arouses any feeling.

> On the other hand, musical sound is too limited in its qualitative variety of tones. . . . this limited circle of pure sounds must be broken, and the infinite variety of *noise-sound* conquered.
>
> We Futurists have deeply loved and enjoyed the harmonies of the great masters. For many years Beethoven and Wagner shook our nerves and hearts. Now we are satiated and we find far more enjoyment in the combination of the noises of trams, backfiring motors, carriages and bawling crowds than in listening again, for example, to the *Eroica* or the *Pastorale*.
>
> Away! Let us break out since we cannot much longer restrain our desire to create finally a new musical reality, with a generous distribution of resonant slaps in the face, discarding violins, pianos, double-basses and plaintive organs. Let us break out!
>
> We want to attune and regulate this tremendous variety of noises harmonically and rhythmically.[4]

Russolo wanted to extend the accepted spectrum of music by introducing nonmusical sounds in a controlled fashion. With the help of the painter Ugo Piatti, he designed and built various mechanical noise-producing instruments. He called them *intonarumori* ("noise-intoners") and built them to produce "families" of sounds, ranging from "roars" (thunders, explosions, etc.) to whistles (hisses, puffs), whispers (murmurs, grumbles), screeches (creaks, rustles), percussive noises (metal, wood), and voices of animals and humans.

Russolo designed and constructed noise-intoners for each of his six categories of sounds. Outwardly, each instrument consisted of an oblong wooden box with a large metal megaphone attached to amplify the sound. Inside, there were various mechanical devices used to generate the desired sounds by turning cranks, tapping stretched membranes, and other means. Some had levers and wires to rattle pots or cardboard canisters filled with objects. One used an air bellows to create wind or breath sounds. Another used a skin stretched like a drum head that, when scraped or tapped across its diameter, produced a sequence of pitched tones. This last type of noise-intoner was used to imitate the starting of an automobile engine. Russolo also found that he could adjust the timbre of these stretched membranes by preparing them beforehand using various chemical baths. The noise-intoners were mostly played by holding a lever with the left hand to control the pitch range and turning a crank with the right hand to evoke the noise.

In addition to constructing his instruments, Russolo immersed himself in writing music for ensembles of noise-intoners. He was not a trained musician, so his scores consisted of verbal and graphic instructions, foreshadowing the use of graphical scores by electronic music composers decades in the future.

By April 1914, an entire orchestra of roarers, whistlers, whisperers, screechers, and howlers had been constructed, and Russolo's first concert was performed in Rome. The instruments were played in unison to create a variety of sound environments reminiscent of the city and nature. The works had titles such as *Awakening of Capital*, *Meeting of Cars and Airplanes*, *Dining on the Terrace of the Casino*, and *Skirmish in the Oasis*. This performance is legendary because of the public disturbance that ensued. Scores of rotten fruits and vegetables were hurled at the performers for the duration of the concert.[5] The event was topped by the arrest of Marinetti and Russolo for having incited a riot.

Bruised but triumphant, Russolo and Marinetti next presented a series of twelve performances in London in June 1914. The ensemble was arranged on stage with the megaphones of the noise-intoners aimed squarely at the audience. Behind the sizable boxes stood the musicians, each positioned with a music stand and Russolo's large sheet music perched on top. This must have been a comical and puzzling sight for most listeners, considering the music of noises that emanated from the stage. Marinetti remarked that playing the noise-intoners for the unsuspecting public was like "showing the first steam engine to a herd of cows."[6]

A critique of the event in the *Times* of London summarized the public's reaction to this music by likening the sounds to those "in the rigging of a channel-steamer during a bad crossing." This critic suggested that it had been "unwise" of the musicians to proceed after their first piece was greeted by "the pathetic cries of 'no more' from all parts of the auditorium." Marinetti himself claimed that the performances were a huge success and attracted as many as 30,000 people.

Russolo received a serious head injury during World War I, but after a long recovery period returned to Paris to continue his exploration of noise-making machines. One was the Rumorarmonio—the "noise harmonium"—which put several of his noise-making devices under the control of a piano-style keyboard. One firsthand account of the Rumorarmonio described it as an elaborately modified piano whose mechanical action struck metal plates, rattled porcelain, and drew croaking noises and "choked calls, cries" from its insides.[7]

Sadly, all of Russolo's scores and noise-intoners were lost during World War II, and only one extremely poor recording exists of one of his performances (Paris, 1921). Pierre Henry (b. 1927) composed an homage to the Futurists in 1975 that employed several newly constructed versions of Russolo's noise-intoners. In addition, the Foundation Russolo-Pratella has, since 1979, undertaken a revival of Futurist music using notes and firsthand accounts from Russolo's time to recreate his instruments and music.

Back in France, Erik Satie had joined forces with the playwright Jean Cocteau to present a "ballet" called *Parade* in 1917. With sets by Pablo Picasso and choreography by Leonid Massine, this work was a pivotal piece of avant-garde craftsmanship. Cocteau characterized the ballet as a manifesto of cubism. The stage was filled with a variety of nonsense activities, including the antics of a Chinese magician, a dancer who mimed the riding of a horse and swimming in a river, and a troupe of acrobats flying across the stage. It was Satie's music that caused the biggest uproar. Not only did it nonchalantly move from ragtime to classical motifs but it included such nonmusical sounds as the pounding of a typewriter, a steamship whistle, a siren, and an airplane motor. The audience revolted and the newspapers denounced the spectacle. In one reply to a critic, Satie simply wrote:

> Sir and Dear Friend,
> You are not only an arse, but an arse without music.
>
> Erik Satie

Chapter 4

ELECTRONIC PIONEERS: CAHILL, THEREMIN, MARTENOT, TRAUTWEIN, AND HAMMOND

The technology of electronic music has a longer history than many might imagine. Rudimentary experiments in the electrical production of sound were taking place before the invention of the light bulb. The principles of electricity were hardly understood until the late 1800s. At that time, any discussions of oscillating electrical waves—or oscillating anything, for that matter—were strictly within the purview of science. The German physicist Hermann von Helmholtz, a prominent scientist of the late 1800s, illustrated many of his theories about electromagnetic wave action by using tuning forks and musical demonstrations. It wasn't long until inventors began to find a way to apply these ideas to the electrical creation of musical sound.

Some of the earliest devices that produced sounds electrically were the results of experimental accidents that remained largely misunderstood by their inventors. In 1837, one Dr. C. G. Page of Salem, Massachusetts, reported in the *American Journal of Science* that he had discovered a way of generating a "distinct ringing sound" by toying with the action of horseshoe magnets and a spiral of copper wire with its ends connected to a zinc-lead battery. He called the result "galvanic music," and although he was at a loss to explain the phenomenon, he had stumbled on a way of producing fairly pure electronic sounds. Similar experiments were conducted by others, but no one seemed successful in applying this discovery to the design of a musical instrument.

The first actual electronic musical instrument was invented in 1874 by American Elisha Gray (1835–1901). Professionally, he was involved in the field of telegraph communications. He obtained his first telegraph patent in 1867 and was employed by the Western Electric Company as a