DEVELOPMENT AND PRACTICE OF ELECTRONIC MUSIC

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EDITORS

The Development and Practice of Electronic Music

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The Development and Practice of Electronic Music

Preface

This book is intended for three groups of readers: the layman with an interest in electronic music, the student working in the field, and the musician who wishes to broaden his knowledge of the art outside his own specialty. Until recently it has been difficult for the reader to gain a comprehensive view of the field of electronic music because the literature has been either too general or too specialized. The initial articles which appeared in the popular press usually focused on the aesthetic implications of electronic music at the expense of describing how the music was produced.

Composers writing about their own works responded by elaborating theories of compositional technique which in retrospect often appear to be justifications of their work rather than explications of techniques used in its production. Throughout the 1950s many critics felt that there was something wrong about using machines to create music, and in turn many composers often gave the impression that traditional musical means and materials had no place in contemporary music.

Since the development and practice of electronic music has been largely tied to technological innovation, it is not surprising that much of the literature has been highly specialized. Articles about new circuits or mechanical devices useful to the production of electronic music were written by engineers. Composers attempted to write about problems that required a knowledge of electronics or psychoacoustics which they did not possess.

In the last decade it has been common for composers to receive the training necessary to handle these problems, and today it is not unusual for a young composer to have competence in computer programming or to be able to design electronic equipment. Also the field has become large enough to accommodate engineers who specialize in the needs of composers and performers. In the last three years at least a dozen books about electronic music have appeared in which for the first time, the authors have attempted to offer a comprehensive view. Electronic music evolves continuously as technology evolves. New media appear, merge into one another (multimedia, intermedia), are transformed, refined, superseded. To write about the present is already to write history since the state of the art changes not by decades, but by days and hours. Perhaps because of the very speed of change we lose a sense of where we have come from—which "new" ideas are actually old ones transistorized or digitized.

To put recent history in perspective with a past already rich in experimental musical ideas the editors called upon Otto Luening to trace the course of experimental music from ancient to modern times. His history is the first chapter of this book. In the quarter century since electronic music first became widely known, a few major trends have emerged distinctly. The editors have focused on four of these, choosing a roughly chronological order. The efforts of the Cologne pioneers in "pure" electronic music (*elektronische musik*) and the research of the Paris group into *musique concrète* can be seen to have merged into what the editors view as *tape studio* music, that is, music made from oscillator or microphone sources by techniques of processing, mixing, and editing with apparatus that is mostly manually controlled. The techniques of the tape studio are discussed fully in Chapter 3 by Gustav Ciamaga.

A second generation in electronic music production is represented by the devices known as voltage-controlled synthesizers, which first appeared commercially in the mid 1960s. The background, operation and compositional implications of the synthesizer are considered in Chapter 4 by Joel Chadabe. The high-speed digital computer gave rise to a third generation in electronic music: a music whose sounds are merely *calculated* as discrete level changes and then made audible by converting numerical values first into electrical values and then, through a loudspeaker, into air pressure values. With a computer and associated equipment the composer can design a "synthesizer" on paper. His studio is never made obsolete since he can rebuild his entire system merely by writing a new program. Several programs for computer-generated music have been invented in the last few years, some highly specialized, others generalized. In Chapter 5 John Rogers discusses how one major music-generating program works and how a composer might use the program to make a piece.

Paralleling the developments in the electronic music studio, whether of the tape, synthesizer or computer variety, there has been remarkable innovation in the art of "real-time" or live-electronic music techniques. Live-electronic musicians have been highly imaginative in incorporating new technologies like video and laser into their work, and their efforts often involve collaborations between visual and plastic artists, filmmakers and engineers. Gordon Mumma details the development and practice of live-electronic music in Chapter 6.

It is impossible to understand how electronic music systems operate without some degree of understanding of electronics and acoustics. For this reason Wayne Slawson's chapter on sound, electronics, and hearing has been made the second chapter of the book. From the beginning it was the editors' conception that each chapter should be the work of a specialist in one area of the field who was also a composer, and that the writing should be directed not at the technically trained person but at the general reader. While the chapters were organized so that they could be read independently of each other, the reader will find that Chapter 2 lays important technical groundwork for the concepts presented in Chapters 3–6. Photographs and inserts have been chosen to draw as broad a picture as possible of the diversity of studios, synthesizers, and composers in the field of electronic music, and the selective bibliography and discography will guide the reader in further research or in building a representative library.

The theory advanced a few years ago by Leonard B. Meyer that a period of stasis in the evolution of musical style would shortly arrive has not proven to be correct. Innovation is still the prime force in new music, but composers continue to absorb the techniques of the past. Thus electronic music—which, according to its first European and American practitioners, meant the end of performance—is now becoming a performance art. Many of those who thought the first synthesizer would replace the tape studio still find it necessary to splice tape and to use natural sound sources. The early predictions that the use of digital computers would do away with the need for tape studios, synthesizers, and even the composer himself have been revised. It appears that in the future electronic music will integrate all of these approaches, as seen in the recent development of hybrid systems. These systems consist of computer-driven synthesizers (which also have the capability of imitating natural sound sources) that are portable, and that can be used in live performance settings, with or without conventional musical instruments.

The future will no doubt see these hybrid systems become as accessible to the layman as the piano in terms of cost and ease of use. Such electronic music systems could have an even more profound influence on our musical culture by making it possible to eliminate the distinction between creative and performance skills, as is the case in many other cultures, and thereby making it possible for anyone to assume interchangeably the roles of composer, performer, and listener. As hypothetical as this may seem, this book testifies to the rapidity with which hypothesis can become reality.

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Origins

OTTO LUENING

Each chapter in this book represents a fragment of a more comprehensive history that could be written a hundred years from now. The technological aspects of music have concerned theorists and composers for many centuries. After reading the following chapter, one must admit that it is not the idea of electronic music that is new, but rather the means to realize the dreams of such diverse figures as the Roman architect Vitruvius, the sixteenth-century English philosopher and scientist Francis Bacon, and Beethoven's contemporary Johann Maelzel.

Otto Luening, together with Vladimir Ussachevsky, was the first American composer to systematically explore what was formerly called "tape music" in the United States. His account of the history of electronic music becomes personal when he describes his meeting with Ferruccio Busoni in 1917. Both Luening and Gordon Mumma (the author of the last chapter in this book) present "histories" of how electronic music developed in the United States, yet at times, it is hard to believe that they are talking about the same subject. Together, they represent an approximation of the evolution of electronic music in the last thirty years. They give us an insight that can only be provided by innovative composers who have been in the midst of all that has happened to music in the recent past.

Otto Luening was born in Milwaukee, Wisconsin in 1900. He heard about electronic sound as a possible compositional tool in 1918 from Ferruccio Busoni, with whom he was studying in Zurich. Luening's career has been distinguished by his diverse activities as flutist, opera conductor, and accompanist. He is one of the Directors of the Columbia-Princeton Electronic Music Center, a former member of the Julliard School faculty, and Professor Emeritus at Columbia University, where he taught composition and conducted opera for twenty-five years. He is a member of the National Institute of Arts and Letters, and was for many years a Trustee of the American Academy in Rome and on the Educational Advisory Board of the Guggenheim Foundation.

Luening's more than three hundred works in all categories include *twenty-two compositions with electronic sound, eleven of these produced in collaboration with Vladimir Ussachevsky.*

Electronic music is a generic term describing music that uses electronically generated sound or sound modified by electronic means, which may or may not be accompanied by live voices or musical instruments, and which may be delivered live or through speakers.

Alongside the history of accepted and established styles of music, one can trace a long line of experiments that were sometimes unsuccessful, sometimes eventually successful, and sometimes incorporated into the mainstream of music only after a long period of time. Composers and theoreticians with advanced pioneering ideas and accomplishments run like a thread through the history of music; the advanced musician of today has not been alone in his search for new horizons. The historical record contradicts the premise that everything was invented yesterday, thus setting the contemporary scene in the proper perspective without in any way detracting from its importance.

Studies in sound and sound transmission began in antiquity. In their book, *Man's World of Sound,* J. R. Pierce and E. E. David mention that Sanskrit grammarians of the third and fourth centuries B.C., notably Panini, showed the relationship between the sounds of language and the position of the mouth, an experiment that anyone can conduct by opening and closing the mouth as if yawning and tapping the side of the cheek.

In the seventeenth century, the relationships between tongue and lip positions in producing voice sounds were more precisely systematized, and, soon after, drawings of these mouth positions were made. In the nineteenth century, Alexander Melville Bell, the father of Alexander Graham Bell, developed this concept until it became known as "visible speech." The experiments of the two Bells showed conclusively that they understood clearly the relationship between the vocal tract and the sound produced. This research later became a basis for much of the work they did in developing the telephone. In 1865 Alexander Graham Bell conceived the idea of transmitting speech by electric waves. Ten years later, the principle of reproduction and transmission of sound became clear to him while he was experimenting with a telegraph. In 1876 he was able to transmit a complete sentence; his assistant heard him say quite clearly, "Watson, come here; I want you." He organized the Bell Telephone Company in 1877, and through his Volta Laboratory in Washington, D.C., he produced the first successful phonograph record; the photophone, which transmitted speech by light rays; the audiometer; and other inventions, including the flat and cylindrical wax recorders for phonographs.

Interest in sound transmission has continued at the Bell Telephone Laboratories, resulting in inventions such as the Vocoder in the 1930s, an instrument that has strongly influenced the development of electronic music since 1948. Recently, at the Bell Labs, Max Mathews has used a computer to program vocal sounds, and has simulated vocal sounds in the form of song and even choral experiments. Others are now developing this type of sound production.

However, the transmission of sound occupied the minds of men long before the invention of the telephone. Vitruvius, the Roman architect and engineer for Augustus, wrote about the acoustics of theaters in *The Ten Books of Architecture:* "Hence the ancient architects . . . by means of the canonical theory of the mathematicians and that of the musicians, endeavored to make every voice uttered on the stage come with greater clearness and sweetness to the ears of the audience."

In the eighteenth century the Russian professor Kratzenstein produced vowel sounds from tubes to which he fixed a vibrating reed, controlled by air from a bellows. Abbé Mical, a Parisian, and Ritter von Kempelen, a Hungarian, built speaking machines. Properly run, they produced intelligible words and sentences, though they lacked the quality of the human voice.

The development of instrumental sound is equally ancient. In the fifth and sixth centuries B.C., the Greek philosopher and religious teacher Pythagoras discovered the numerical ratios corresponding to the principal intervals of the musical scale. Because of his religious inclinations, he associated these ratios with what he called "harmony of the spheres." He applied these arithmetic ratios to string lengths and to the number of sound vibrations that were produced in this fashion.

In his book, *Genesis of a Music,* Harry Partch states that acoustical studies began in China in approximately 2800 B.C., and that King Fang made a fifty-three tone scale within the octave. Ho Tcheng-Tin, a Chinese, anticipated our present twelve-tone scale by about thirteen centuries. Syu-ma-Ch-ien, an ancient Chinese historian, ascribed acoustical formulas for the pentatonic scale to Ling Lun, a Chinese court musician who lived about 2700 B.C. This ancient history was related by Chu-T'sai-Yu in the sixteenth century A.D., preceding the establishment of equal temperament in the West.

In his *New Atlantis* (1624), Francis Bacon wrote:

> We have also sound-houses, where we practice and demonstrate all sounds, and their generation. We have harmonies which you have not, of quarter-sounds, and lesser slides of sounds. Divers instruments of music likewise to you unknown, some sweeter than any you have; together with bells and rings that are dainty and sweet. We represent small sounds as great and deep; likewise great sounds extenuate and sharp; we make divers tremblings and warblings of sounds, which in their original are entire. We represent and imitate all articulate sounds and letters, and the voices and notes of beasts and birds. We have certain helps which set to the ear do further the hearing greatly. We have also divers strange and artificial echoes, reflecting the voice many times, and as it were tossing it: and some that give back the voice louder than it came; some shriller, and some deeper; yea, some rendering the voice differing in the letters or articulate sound from that they receive. We have also means to convey sounds in trunks and pipes, in strange lines and distances.

This is a remarkable prophecy of electronic music as it has developed in the twentieth cenutry.

E. T. A. Hoffmann (1776–1822), the German author, musician, painter, and jurist, now known chiefly as the hero of Offenbach's opera, *The Tales of Hoffmann,* wrote a story called "The Automaton." In it he wrote about the function and meaning of music and the development of all sorts of new glass and metal instruments. He stated that higher musical principles recognize the most unusual sounds in nature and make the most heterogenous bodies resonate, but that the composer needs to combine this mysterious music into a form comprehensible to the human ear. He said, further, that any attempts to produce sound from metal strips, glass threads, glass cylinders, strips of marble, and from strings vibrating and sounding in unusual ways were significant contributions to the development of music. Hoffmann said that these attempts to penetrate the deep secrets hidden everywhere in nature would only be retarded if the commercial exploitation of inventions took place before they had been perfected. In conclusion, he stated that the aim of the musician was to discover the perfect tone, one that becomes more perfect as it relates to the secret sounds of nature, some of which can still be heard on earth. He wrote that in primitive times music was filled with poetry and with the divine instinct of prophecy, and that the legend of the music of the spheres was an echo of that mysterious primeval time in which music had the power to effect communion with the supernatural. Hoffmann exerted a strong influence on the Italian composer Ferruccio Busoni, who lived well into the twentieth century.

Early technical experiments and developments are equally fascinating when we compare them to what is happening today. Don Nicola Vicentino (1511–72), the Italian composer and theorist, was a Renaissance artist who combined historical findings with creative works. He attempted to revive some of the Greek modes and other musical practices in his compositions. He also invented an "Archicembalo," a harpsichord-like instrument with six keyboards and thirty-one steps to an octave. His ideas aroused much opposition, but he influenced subsequent generations.

Another inventor, the Jesuit priest Athanasius Kircher, described in his book, *Musurgia Universalis* (1660), a mechanical device that composed music. He used numbers and arithmetic-number relationships to represent scale, rhythm and tempo relations; hence, the name "Arca Musarithmica."

Johann Quantz, C. P. E. Bach, Johann Philipp Kirnberger, Michael and Joseph Haydn, and W. A. Mozart were all interested in automatic music. Mozart wrote beautiful works for mechanical organ, works for which he made many sketches and revisions. The mechanical organ for which he composed was an artificial playing apparatus consisting of levers, wires, springs, and toothed wheels. Compositions were written for other mechanical instruments, including one in the form of a Rococo lady playing a piano, Pan blowing the flute, and two muses playing flute and piano, with small canary birds trilling in their cages; other figures in Spanish costumes played flutes. They were all machines, small and large masterworks of the mechanical art.

Abbé Delaborde constructed a "Clavecin Electrique" in Paris in 1761. The specifications for this instrument are in the Library of the American Philosophical Society in Philadelphia. One can speculate whether Benjamin Franklin, who was interested in music, had any knowledge of this instrument; he perfected the glass harmonica at about the same time, and conducted some experiments in underwater acoustics.

Beethoven's contemporary Johann Maelzel invented several mechanical instruments, including a chess player, the metronome, a mechanical trumpeter, and the "Panharmonicon" for which Beethoven composed a piece to commemorate the Battle of Vittoria.

An "Electromechanical Piano" was invented by Hipps, the director of the telegraph factory in Neuchatel, Switzerland in 1867. It used an electromagnet. Elisha Gray's "Electromusical or Electroharmonic Piano" was demonstrated in Chicago in 1876. In Philadelphia the same year, Koenig demonstrated his "Tonametric" apparatus, which divided four octaves into 670 equal parts.

In 1895 Jullian Carrillo, a Mexican composer of Indian heritage, wrote music in quarter tones and investigated other scale formations. He subdivided the octave into ninety-six intervals, constructed instruments to reproduce divisions as small as a sixteenth tone, and brought us to the threshold of some twentieth-century discoveries. He demonstrated his microtonal instruments in New York in 1926. These included an "Octavina" for eighth tones and an "Arpa Citera" for sixteenth tones. By 1929 Alois Hàba had composed an opera in quarter tones; Hans Barth, a quarter-tone concerto for piano and strings; and Iwan Wysch-Negradsky, a harmony textbook for composing with quarter tones. These and Busoni's experiments with a Harmonium in third tones were preparations for electronic instruments that were not exclusively tied to the scales in use at that time.

The technical development of instruments was highlighted by Edison's patent for the phonograph (1878), Helmholtz's book, *Sensations of Tone* (1885), the invention of the Emile Berliner telephone transmitter and disc record (1897), and the work of W. C. Sabin, P. M. Morse, Lord Rayleigh, Dayton Miller, Harvey Fletcher, and other scientists. In 1897 Berliner perfected the Berliner disc, which made phonograph records commercially feasible. To put these events in perspective, the Sioux Indians fought their last battle at Wounded Knee in 1890.

In July, 1906, *McClure's Magazine* published an article by Ray Stannard Baker entitled "New Music for an Old World . . . Dr. Thaddeus Cahill's Dynamophone—An Extraordinary Electrical Invention For Producing Scientifically Perfect Music." Excerpts from the article indicate the fascination with which the Dynamophone was received:

> Largest Musical Instrument Ever Built, ... instead of bringing the people to the music, the new method sends the new music to the people. . . . by opening a switch we may 'turn on' the music . . . . Democracy in Music . . . . Dr. Cahill's instrument, without in any way overestimating its capabilities, or suggesting that it will displace the present forms of musical art, gives us a hint of what the music of the

> future may be like. . . . the best music may be delivered at towns, villages, and even farmhouses up to a hundred miles or more from the central station. Small country churches, townhalls, schools, at present holding up no ideals of really good music, may be provided with the same high class selections that are daily produced by the most skillful players in the cities . . . . A HUNDRED INSTRUMENTS IN ONE . . . . Lord Kelvin encourages the inventor . . . . Electricity used to Produce Music . . . . Learning to Play the Dynamophone. . . . learning to play the new instrument has been like some new wonderful discovery in an unknown musical world. Here were limitless musical possibilities waiting to be utilized. The musician uses his keys and stops to build up the voices of flute or clarinet, as the artist uses his brushes for mixing color to obtain a certain hue. . . . the workmen in the shop speak of 'electric music.' In the end the public will probably choose its own name . . . . WE SHALL KEEP THE OLD WITH THE NEW. . . . but it would be absurd to say that the new instrument will even seriously interfere with the presentation of great music of any sort. It will rather add to the public interest in music and the appreciation of musical art. . . . we welcome the new with eagerness; it has a great place to fill; it may revolutionize our musical art; but, in accepting the new, we will not give up the old.

Shortly after Dr. Cahill gave a demonstration in Holyoke, Massachusetts, the celebrated Italian pianist and composer Ferruccio Busoni wrote his "Sketch of a New Aesthetic of Music." In this remarkable collection of "notes," as he called the booklet, he questioned much in the prevailing music practice and pointed out some new possibilities. He wrote that art forms last longer if they stay close to the essence of each individual species. He suggested that music is almost incorporeal (he called it "sonorous air"), almost like Nature herself. He opposed formalism, systems, and routine, but asserted that each musical motive contains within itself its "life germ," the embryo of its fully developed form, each one different from all others. He proclaimed that the creative artist does not follow laws already made, but that he makes laws. Busoni decried a too rigid adherence to existing notation, and said that the terms "consonance" and "dissonance" were too confining. He suggested an expansion of the major-minor chromatic scale and constructed 113 other scale formations within the octave.

Busoni predicted a revolution in the field of harmony. He was convinced that instrumental music had reached a dead end and that new instruments were needed; he suggested a scale of thirty-six divisions within the octave as an interesting possibility for new music. He wrote:

> Fortunately, while busy with this essay, I received from America direct and authentic intelligence which solved the problem in a simple manner. I refer to an invention by Dr. Thaddeus Cahill. He has constructed a comprehensive apparatus which makes it possible to transform an electrical current into a fixed and mathematically exact number of vibrations. As pitch depends on the number 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 . . . . Only a long and careful series

of experiments, and a continued training of the ear can render this unfamiliar material approachable and plastic for the coming generation and for Art.[1]

Edgard Varèse, in a reminiscence of Busoni, said:

> In 1907, still in my early 20's, I went to Berlin, where I spent most of the next seven years, and had the good fortune of becoming (in spite of the disparity of age and importance) the friend of Ferruccio Busoni, then at the height of his fame. I had read his remarkable little book, "A New Aesthetic of Music," a milestone in my musical development, and when I came upon, "Music is born free; and to win freedom is its destiny," it was like hearing the echo of my own thought. . . . He was very much interested in the electrical instruments we began to hear about, and I remember particularly one he had read of called the "Dynamophone," invented by a Dr. Thaddeus Cahill, which I later saw demonstrated in New York. All through his writings one finds over and over again predictions about the music of the future which have since becomes true. In fact, there is hardly a development which he did not foresee, as, for instance, in this extraordinary prophecy, "I almost think that in the new great music, machines will also be necessary and will be assigned a share in it. Perhaps industry, too, will bring forth her share in the artistic ascent!"[2]

Two years after Busoni published his booklet, the Italian Marinetti published in *Le Figaro* (Paris) his "Futurist Manifesto," which called for a worldwide artists' revolt against the ossified values of the past, represented by the "Establishment." The movement spread rapidly to Germany, Russia, and Switzerland.

"The Art of Noises," compiled in 1913 by Luigi Russolo, a Futurist painter, is still of interest.[3] He suggested fixing the pitch of noise sounds, and classified them as follows: Group I—booms, thunder claps, explosions, crashes, splashes, roars; Group II—whistles, hisses, snorts; Group III—whispers, murmurs, mutterings, bustling noises, gurgles; Group IV—screams, screeches, rustlings, buzzes, cracklings, sounds by friction; Group V—noises obtained by percussions or metals, wood, stone, and terra-cotta; Group VI—voices of animals and men, shouts, shrieks, groans, howls, laughs, wheezes, and sobs. Russolo implemented his catalogue of noises by building a whole collection of noise-making instruments. As Varèse saluted Busoni, so did Pierre Schaeffer acknowledge Russolo, calling him the originator of the concept of noise montage, which was developed at the Centre d'Étude of the Radiodiffusion Télévision Française by mid-century.

Futurism became Dadaism when Tristan Tzara coined the term in 1916

[1] Ferruccio Busoni, *Sketch of a New Aesthetic of Music* (New York: G. Schirmer, 1911), p. 33.

[2] *Columbia University Forum* (Spring, 1966), 20.

[3] Nicolas Slonimsky, *Music Since 1900* (New York: Charles Scribner's Sons, 1971), pp. 1298–1302.

in Zurich. His recipe for making a poem still has a bearing on some of today's artistic manifestations.

> . . . cut out the single words of a newspaper article, shake well in a bag, take them out one by one and copy them down in the order in which you picked them and you will have a beautiful poem.

Between Busoni's booklet and the advent of Dadaism, Schönberg wrote his *Harmonielehre* (Universal Edition, 1911). In this important book, triadic harmony evolved systematically and logically to a system of chords built on perfect fourths. The work ends with a prophetic statement about timbre melodies. In 1913 the Paris premiere of Stravinsky's *Rite of Spring* took place. Orchestral rhythm, timbre, and dynamics were given a new dimension, and the work had a profound effect on composers and, indeed, on the art world in general.

When I met Busoni in Zurich in 1917, his views about composition had changed since 1907. He had met the German-American theorist Bernhard Ziehn in Chicago. In 1887 Ziehn had published a remarkable harmony text that developed a system of symmetrical inversion based on the old Contrarium Reversum. When Busoni met him in 1910, Ziehn was engaged in developing a system of canonical techniques.

In his Zurich years Busoni assumed that composers who showed him scores would have mastered technical problems by themselves. He expected experimentation and analysis—novelty for its own sake no longer interested him. He talked of form, not formula; he talked more often than in the past of taste, style, economy, temperament (human, not musical!), intelligence, and equipoise.

In the early twentieth century, technical developments became far more important than either artistic speculation or musical experimentation. The idea of the steel-wire recorder was developed by Valdemar Poulsen of Copenhagen around 1902. Lee De Forest, with inspired vision, thought first of the "Audion" (now called the "Triode") in 1906. This and his three hundred other patents had a decided influence on modern communications. Satie used dynamo and airplane sounds in his *Ballet Parade* (1917). In the early 20s Varèse suggested greater cooperation between composers and engineers, a point of view repeated by Carlos Chavez in his *For A New Music* (W. W. Norton & Company, Inc., 1937). Between 1906 and 1920, radio and phonograph techniques were perfected.

At the meeting of the Eighth Soviet Congress in 1920, the physicist Leon Termen demonstrated the first model of his new instrument, which later became known as the Theremin. The sounds were produced by hand movements in the air. Several composers used it in their compositions: Paschtschenko, Schillinger, Slonimski, Varèse, Martinu, Fuleihan, and Percy Grainger, a pupil of Busoni's who since 1895 had been developing a "Free Music" with eighth tones and complete rhythmic freedom of the single voices. Grainger's music was notated on graph paper, and he himself built machines for it.