THE EVOLUTION OF ELECTRONIC MUSICAL INSTRUMENTS IN THE UNITED STATES

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This volume is dedicated to my loving wife Tricka.

TABLE OF CONTENTS

Chapter

CHAPTER I

ELECTRICAL MUSIC PIONEERS

> The trouble about these beautiful novel things is that they interfere so with one's arrangements. Every time I see or hear a new wonder like this I have to postpone my death right off. I couldn't possibly leave this world until I have heard this again and again.
>
> - - - Mark Twain, on hearing the Cahill Telharmonium (1906).[1]

From the composer's viewpoint, the history of electronic music, _per se_, begins with the advent of magnetic tape manipulation. However, experimentation with electrical _means_ of producing musical sounds predates the arrival of the tape medium by more than a century.

The earliest use of electricity in musical instruments was in motor-driven acoustical instruments such as Hipp's _Electromechanical Piano_ (1867).[2] This kind of device, which used electricity solely as a motive power, would not be included in a discussion of electronic musical instruments, defined as devices in which periodic electric currents are generated and controlled, and translated into sound. The author has adopted such a definition for this discussion.

Many of the early discoveries in electrical music came about accidentally, as the by-product of experiments concerning the general behavior of electricity. This was the case in the production of galvanic music[3] by Dr. C. G. Page of Salem, Massachusetts, in 1837. Page was experimenting with several horseshoe magnets and a coil attached to a battery. He noticed that when one or both poles of the magnet were placed by the coil, a distinct ringing was heard in the magnet when connections to the battery were either broken or made. Page was evidently not aware of the elementary properties of coils, for he suspected that the ringing was caused by reverberation from the loud snap made when the connection was broken. To test his theory, he removed the battery to a considerable distance and repeated the experiment. The results were, of course, identical. Page had inadvertently discovered the principle of the electronic tuning fork. News of Page's discoveries reached France, where C. E. J. Delezenne duplicated and expanded upon Page's experiments.[4] Evidently, neither of the gentlemen produced a recognizable musical instrument utilizing the principles they had discovered.

In 1839, Neef designed a system in which a spring and a magnetized bar interacted to cause vibrations in a steel armature.[5] In 1885, the German Ernst Lorenz patented an instrument using a similar design.[6]

Lorenz's instrument embodied two kinds of devices. The first was a circuit interrupter which served to create periodic electrical currents. The circuit interrupter used an electromagnet to attract a metallic bar. A small clapper on a spring mounted above the bar then broke the circuit and forced the bar to return to its original position. The cycle was repeated, creating periodic electrical currents. The electrical vibrations produced were used to drive an electromagnet in the second device, a resonator. This electromagnet was placed adjacent to a metallic membrane which was connected to resonating boards, translating vibrations into sound. The instrument consisted of a complete set of the current interrupters (creating appropriate frequencies) and a resonating device. Lorenz indicated that "suitable resistances" could be added to the circuit to give control over the "growing and dying" of the tones. He suggested that pedals might be used to control this rudimentary system of envelope control.

In 1899, William Duddell, an English physicist, discovered that the carbon arc lamp used for lighting could be made to produce musical notes. The <u>Singing Arc</u> consisted of a direct current arc and a shunt circuit. This circuit acted on the arc, causing regular fluctuations in the discharge and created a musical tone. The pitch and intensity of the note produced depended upon capacity, induction, resistance in the secondary circuit, and the potential difference of the arc terminals. High potentials gave clear notes, and the pitch produced from combinations of inductances and capacitances could be approximated by the formula:

$$\frac{1}{2\pi\sqrt{LC}}$$

(where L is inductance in henries, and C is capacitance in farads.)

Duddell built a keyboard which controlled the characteristics of the secondary circuit, causing the arc to produce musical notes.

When Duddell played his Singing Arc before the London Institution of Electrical Engineers, arc lights in two nearby laboratories also played tunes during the time of the demonstration. At first, no explanation could be given, but it was later determined that the arc lights were on the same circuit with Duddell's musical arc. When the Singing Arc was played, it produced variations in the main line, thus accounting for the strange behavior of the other arc lights. The possibility that several arcs could be played at a distance from one keyboard led to speculation that concerts might be given in conjunction with lighting service.

Duddell, however, did not pursue the matter, abandoning his application for a British patent.

Even though the Singing Arc did not become a popular musical instrument, it is important historically, for it was probably the first totally electric musical instrument.

Against the background of these early experiments with electricity and music, the electromagnetic musical system designed and built by the American inventor Thaddeus Cahill stands as the *tour de force* of early electrical musical instrument construction. Unlike the designs of some of the previous instruments, which were serendipital by-products of experimentation with electricity, the construction of this electrical music system was no accident. Cahill spent more than a decade designing, constructing, and improving his invention.

During his teens, Thaddeus Cahill (born 1867) became intensely interested in the physics of music and began making experiments in electrical music which would eliminate what he considered to be "defects" in acoustical instruments. He lamented the lack of chordal capacity in the violin, the "dwindling" of the tone once the piano is struck, and the lack of expressive control of the organ. Cahill felt that it should be possible to construct a machine that would give the performer "absolute control" over the tones produced, though his first experiments showed little success in attaining this end.

Cahill nurtured these ideas, which would eventually result in his Art of and Apparatus for Generating and Distributing Music Electrically, through his college days in 1884 at the Oberlin Academy. Cahill became dissatisfied with scholastic life and withdrew in order to devote his time to perfecting his early music experiments and several other inventions, including an electric typewriter, a music composing machine, and a scheme for floodlighting baseball parks. Between 1885 and 1888 he divided his time between inventive work, in which his father and brothers encouraged him, and college studies under private tutors. In 1899, Cahill went to Washington, D.C. where, at the same time he held posts such as Stationery Clerk of the House of Representatives, he managed to find time both for inventive work and the legal studies which eventually culminated in his admission to the bar.

This background, coupled with Cahill's talent for invention, gave him the opportunity to bring his ideas to fruition, the legal expertise to protect his inventions with patents, and the business acumen to interest investors in what may be regarded as the most ambitious commercial undertaking in the history of electrical music.

Cahill was not satisfied with building only an instrument which would offer "absolute" control over sounds. He also envisioned an early Muzak-type service in which music would be distributed by wire to thousands of distant subscribers.

Some experimentation had already taken place in which concerts were transmitted by telephone, but Cahill pointed out that the sounds produced were so feeble that the telephone receiver had to be held close to the ear. Cahill constructed his electrical system in order to produce a current of as much as one ampere, a much higher level than the telephone receiver normally handled. He built speakers for his electric music system designed to flood the room with sound.

Unfortunately, Cahill's designs predated some important technological developments which would have greatly aided his electrical music system. Lee DeForest's "audion" (triode tube), which has since become the basis of modern amplification principles, appeared the same year (1906) that Cahill finished his most complex apparatus. Within ten years, Dr. H. D. Arnold and others at the Bell Telephone Laboratories perfected the vacuum tube amplifier to the point where it could be used on transcontinental telephone circuits.

Without benefit of these devices, Cahill had to develop a system that would generate currents strong enough to drive speakers without the use of an amplifier. Cahill accomplished this by employing huge rotating elements that traveled at the proper speed to produce electrical oscillations corresponding to frequencies of the musical scale. This construction, and Cahill's announced plans to distribute music over telephone wires, gave rise to such descriptive names as Dynamophone and Telharmonium for the device. Cahill preferred the name Dynamophone, but Telharmonium was generally adopted by the public.

Of all electrical musical instruments, the Telharmonium was the largest and heaviest, weighing over two hundred tons and comprising many rail flatcars of equipment. These gargantuan dimensions were dictated because the machine was designed for a twelve to fifteen kilowatt output for each rotating element, without benefit of amplification.

With the exception of amplification devices, the Teleharmonium embodied most of the salient features found in successful electronic musical instruments of today; i.e., it had an "oscillator" or source of electrical vibrations; timbre control capability through additive synthesis of sine tones; envelope shaping, featuring a touch sensitive keyboard;

and speakers to give voice to the electrical vibrations.

Cahill's exhaustive description of the Telharmonium is contained in five patents issued during the years 1897-1919.[7]

Cahill's first instrument produced electricalloscillations by using simple rotating tone wheels, or "rheotomes," having alternating sections of conducting and insulating material which served to interrupt regularly an electrical circuit. The brushes which made contact with these rheotomes were situated in such a way as to produce an alternating current, a requisite for tone production. By manipulating the speed at which these tone wheels revolved and the number of alternating insulating and conducting sections used, Cahill created the electrical oscillations necessary to produce the musical tones desired.

Cahill's first patent (1897) illustrates the preferred arrangement of these rheotomes. The individual rheotomes were grouped on twelve long shafts traversing the length of a supporting platform. Each shaft represented a particular pitch, hence the name "pitch shaft." The rheotomes were arranged in groups of six, producing a fundamental note with five overtones. Cahill referred to each group of six rheotomes as a "rheotome-cylinder." Each pitch shaft carried seven rheotome-cylinders which produced a particular note throughout seven octaves (with associated overtones in each octave). Thus, with twelve pitch shafts Cahill created an instrument with a range of seven octaves with control over fundamental and overtones in each octave. Only the highest octaves used fewer than six rheotomes to a rheotome-cylinder, thereby reducing the number of overtones available in those octaves.

Cahill pointed out several ways of constructing these pitch shafts to create a scale, but indicated his preferred scheme of constructing twelve identical pitch shafts with associated rheotomes and rotating each shaft at a different speed, proportional to the vibration frequency desired. That is, the pitch shaft producing the note c-sharp rotated slightly faster than the shaft producing c, and so forth, producing a chromatic scale.

In Cahill's first design, a system of pulleys and belts was used to drive the twelve pitch shafts from a single engine. The engine was connected to twelve pulleys that differed in diameter in the same ratios as the frequencies of the equi-tempered scale. The pitch shafts were driven by belt from these pulleys, one belt for each pulley and its corresponding pitch shaft. Pitch shaft "c" was rotated at a speed producing the oscillations for the note "c" in its various octaves, complete with overtones; pitch shaft "c", rotating slightly faster, produced all c-sharps, and so forth. The overall pitch level of the instrument could be controlled by varying the speed of the driving motor.

There was considerable duplication among the individual rheotomes. Rheotomes for the fourth partial of the lowest octave, the second partial of the next higher octave, and the fundamental of the succeeding higher octave would create the same frequency due to relationships of the harmonic series.

Cahill was aware of this, for he later devised a switchboard system in which a given rheotome might function as a fundamental in one octave and a second or fourth partial in a lower octave. This design, which resulted in less-complete sets of harmonics in the higher registers and intonation problems with some odd-numbered partials, may have been forced on Cahill by economic necessity. He implied this in a talk before the Music Teachers National Association in 1907, where he stated that three or four hundred rotating elements would be necessary for a truly complete "plant."[8]

The most important feature of Cahill's tone generation system was that perfect intonation could be maintained. Since all octaves of a note were on the same shaft, they would remain precisely in tune. Also, by placing the various overtones of each fundamental on the same shaft, "perfect" harmonics could be maintained, even to the phase relationships. The single remaining source of faulty intonation, slippage in the pulley belts, was eliminated when Cahill introduced a gear-driven arrangement to replace the pulley belt scheme.

Tuning the Telharmonium amounted to tuning only twelve notes (one on each pitch shaft), which would bring all the notes of the instrument into tune. Obviously, tuning to a scale other than the equitempered could be accomplished by changing the ratios of the driving pulleys (or gears).

This prospect caused Busoni to speculate in his Sketch of a New Esthetic of Music that the Telharmonium might offer solutions to problems involved in creating scales composed of microtonal intervals. Some experimentation was done by Cahill's musical staff, utilizing a keyboard with thirty-six keys to the octave. This made performance in equitempered or just intonation possible, but these experiments were essentially intonation studies designed to offer a more "pure" performance of traditional music. No record can be found indicating serious efforts to create microtonal music per se with the Telharmonium. Because of its precision tuning capability, it might have been found to be a useful instrument for the creation of such music.

Cahill had a complete understanding of the requirements for an additive-synthesis timbre control system. The basic concepts of sine wave addition did not, of course, originate with Cahill, but were explained in Helmholtz's pioneering work _On the Sensations of Tone_.

Helmholtz (1821-1894) demonstrated that a musical tone is not a simple sound, but consists of a "ground tone" (fundamental) and various overtones. He further showed that "tone color" or timbre is perceived due to the relative strength of the fundamental and its overtones. He then proved his theories by using tuning forks to "build up" or imitate the tones of various instruments.

Similarly, Cahill used "tone mixers" (transformers) to mix the output of his rheotomes to control timbre. Cahill's early design, with the tone-interrupting rheotomes, required smoothing of the waveform produced. The waveform was fairly complex in harmonic structure, approximating a square wave. Since Cahill wished to produce sine waves which might be mixed in order to create different timbres, he found it necessary to "purify" these complex waves by passing them through a series of inductances. Each time the wave was induced successively from one coil to the next, the higher harmonics were suppressed, leaving a closer approximation of a sine wave. In later designs, these purifying devices were no longer necessary, because Cahill utilized the more complex alternator as the tone generating elements. These alternators were not invented by Cahill, although it is probable that he was the first to adapt them to musical purposes. The alternators used in Cahill's later instruments were designed to produce sine waves needing little modification, making purifying circuits unnecessary.

Cahill employed "stops" similar to those on an organ to govern the relative amplitude of fundamental and overtones on a given bank of alternators. His best instrument offered control over the first eight partials. By blending these partials one could obtain fair approximations of various acoustical instruments and also produce sounds never before heard.

Cahill was also aware that the envelope, or mode of starting, sustaining, and releasing the tone, is as important in characterizing instrumental tones as the timbre. To facilitate envelope control he devised several "expression" devices, including swell pedals and a touch-sensitive keyboard.

The keyboard mechanism employed an extremely complicated electromechanical action which accomplished the goal of bringing two coils into relative degrees of proximity, varying according to pressure exerted on the keyboard. When the key was forced down rapidly, the coils were thrown closer together, allowing a greater current to be induced, therefore causing a louder sound. Conversely, when little pressure was applied to the key, the coils were brought to a position comparatively less close, resulting in pianissimo tones. A later modification allowed "terraced" dynamics on several manuals, much like a harpsichord, each manual being capable of delivering a selected range of the dynamic spectrum, but still retaining touch-sensitive response within that range.

While Cahill indicated that any suitable form of "receiving telephone device" might be used as a vibration translating device (speaker) for the Telharmonium, he described his preferred design which employed an electrically vibrated diaphragm in combination with a horn or suitable reinforcing air chamber. This design represents an improvement over his earlier speaker which employed a wooden sound board set in vibration by several small electromagnets.

Cahill's first complete machine was constructed in

Washington, D.C. During his early residence in Washington, Cahill began to collect the threads of ideas from his boyhood about a complete electrical music system from which one could generate and distribute music. During this time he made one set of plans after another, keeping two draftsmen busy when he could afford to do so. These years of planning and experimentation resulted in the construction of the first Telharmonium in 1900.

The first instrument, though less than perfect, and limited to simple music due to the small (35) number of rotating elements (rheotomes) it employed, was nevertheless sufficiently successful to impress those who heard it.

In 1902, Lord Kelvin, the British physicist, heard the Telharmonium and encouraged the inventor to continue his work. During this period Cahill distributed music by wire from his laboratory to his office or home in another part of the city. Later he distributed electrical music to the residence of George Westinghouse, of air-brake fame, and to the office of a friend in Baltimore.

These experiments attracted the attention of several investors, including the electrical railroading pioneer, O. T. Crosby, and F. C. Todd of Baltimore. Through their financial support, Cahill was able to establish a larger plant in Holyoke, Massachusetts, under the supervision of his brother, Arthur C. Cahill. This plant was under lease to F. C. Todd, President of the New England Electric Music Company.

In 1903, Cahill moved his Washington laboratory to Holyoke to supervise the construction of a larger and more complex version of the Telharmonium which was to be installed in New York City. At this point, Cahill adopted the alternator as the tone generator for the Telharmonium and introduced a gear-drive system to rotate the alternators at appropriate speeds.

Preparations were then made for the commercial debut of the instrument. Several performers, including Edwin H. Pierce, a professional pianist and organist, undertook the task of mastering the new instrument. Demonstrations were made by wire in the Hamilton Hotel in Holyoke, about a mile from the plant.

Descriptions of the music invariably mention the "fullness," "roundness," and "pureness" of the tones, and laud the warmth and flexibility of the musical performance.

Several reporters felt that the Telharmonium was a realization of some of Edward Bellamy's predictions in his utopian novel Looking Backward, which gave a description of how life might be in the year 2000. Bellamy had predicted that one would be able to flood the room with music at the touch of a switch during the twenty-first century. The Telharmonium promised to make this a reality a full hundred years sooner.

Others hailed the Telharmonium as the harbinger of "democracy" in music. The following comments are typical:

> As the machine is developed, and as the players become more expert, we may enter upon quite a new era of music, what may be called, indeed, the democracy of music. We cannot really herald the complete dominance of democracy until we have good music, great pictures, and the best books at the command of every citizen.
>
> . . . .
>
> 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. With its wires spreading in every direction, not only in the streets of cities and into city homes, but by means of a system of long distance transmission, even now quite feasible, 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, town halls, 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 skilful players in the cities.[9]

Electrical music became the latest promise in the budding age of electrical miracles.

In the summer of 1906, the Holyoke Telharmonium was moved to New York City, and the first central plant of the

New York Electric Music Company was established with the intention of distributing music to patrons in New York City, and Hoboken, New Jersey. "Telharmonic Hall" was located at 39th Street and Broadway, New York City, close to the Metropolitan Opera House. The officers of the New York Electric Music Company were: O. T. Crosby, President; F. C. Todd, Vice-President; C. M. Pihl, Manager. Carl Herbert was manager of the Public Entertainment Department. His musical staff consisted of Elliott Schenck, Musical Director; Karl W. Schulz, Assistant Musical Director; and Henry W. Geiger, Harold O. Smith, Christian Schiott, and O. Scheda.

On September 26, the doors of Telharmonic Hall were opened to the members of the New York Electrical Society for the first public Telharmonic concert.[10] The interest in the development of the new electric music was demonstrated by the size of the audience. The audience of nine hundred was three times the number present for an average meeting of the Society.

Mr. Oscar Crosby delivered an address explaining the basic features of the electrical system, pointing out that the plant had a capacity to supply fifteen to twenty thousand subscribers. He also explained that plans were being made to offer four circuits supplying different kinds of music from which subscribers might choose.

Following Mr. Crosby's speech, a program was presented, including several "classical" selections, imitations of instruments, effects such as the passing of a drum and fife corps, and several songs sung by a Miss Fiske with Telharmonium accompaniment. The concert was well received, and afterwards a large number of members of the Society stayed to learn more about the instrument.

Late that fall, Telharmonic Hall was open on a regular basis, presenting public concerts and demonstrations. The musical program included selections such as "Nocturne in E-Flat," by Chopin; "Ave Maria," by Bach-Gounod; "Traumerei," by Schumann; "Norwegian Folk Song," by Olé Bull; and "Minuet," by Paderewski.

Another public demonstration was given November 9, at the Café Martin, one of the first subscribers. The first selection, "It's Nice to Have a Sweetheart," was marred by a faulty diaphragm in one receiver. This was replaced, and the Cafe was filled with sounds of a Norwegian lullaby, chiming bells, and the imitations of many instruments.

After the concert at the Café Martin, the Directors of the company went to the Broadway headquarters, where they inadvertently discovered that a carbon arc light would act as a receiver for the electrical oscillations, "singing" throughout the range of the instrument. This discovery led to speculation that music might be furnished even more cheaply to department stores and factories that used arc lights. A demonstration with the carbon arc was added to the program of daily recitals.

The outlook for the New York Electric Music Company appeared bright; but, unfortunately, flaws in the Telharmonic system proved to be fatal. Edwin Hall Pierce discussed these problems in an article written in 1924, long after the failure of the Telharmonium:

> First; owing to financial considerations, it was put into actual practical use before it was sufficiently perfected, and also before any of the players, notwithstanding the greatest zeal and diligence, had been able to conquer all its technical difficulties.
>
> Second; under these conditions, the players were obliged to render a varied daily program to a most exacting public, with scarcely any opportunity for sufficient undisturbed practice. Quality naturally suffered.
>
> Third; in order to support the great expense of the undertaking, it was necessary to have a very numerous body of subscribers: patronage was the first prompt and encouraging, but vexatious delays were met with in running the necessary wires in various directions, owing to both mechanical and legal difficulties, and many lost interest and cancelled their orders. Consequently only a small percentage of the hoped-for income became available, and the enterprise finally underwent financial failure.

In regard to the instrument not being in all respects perfected, the following were the most outstanding defects:--First; owing to having but eight of the twelve "shafts" originally intended by the maker, there were four major keys (with their relative minors) in which it was impossible to play. Although this left still a wide range of modulation available, any musician will realize that it constituted a very serious drawback.

Second; owing to certain electrical complications too technical to explain here, the instrument was not fitted to the rendering of massive harmony. It was at its best in the use of two-voice and three-voice harmony, which is, of course, not in accordance with the genius of modern music. If, to a chord of three voices, another voice or two was added, the total strength of the chord became not greater, but <u>less</u> than before--a most vexatious and anomalous state of affairs.

Third; owing to certain electrical conditions, when a staccato touch was used, the staccato effect was apt to result in an exaggerated caricature, resembling blows from a tack-hammer. This defect the inventor succeeded in overcoming by a very ingenious device later on, but not until many hearers had become prejudiced against the instrument.

Fourth; although it was possible to produce many beautiful and varied tone-colors, it was impossible to use more than any <u>two</u> of them at once. This limited the opportunity for simulating orchestral effects.

Fifth; the well-known "growling" effect of chords closely grouped in the bass was greatly <u>exaggerated</u> in this instrument, so that harmonies which would have been perfectly agreeable to the piano, organ or string quartet, sometimes needed to be completely redistributed for this instrument. This would not have been an insurmountable obstacle, but was a matter which properly demanded longer specialized study than our working conditions permitted.

Lastly, in spite of the variety of tone-color available, the instrument itself had its own special character which pervaded everything, and which in

> time grew highly irritating to the nerves. All the musical staff agreed in admitting this to each other, though careful not to express their views to the public, nor to members of the company. Personally, I am positive that subscribers would have soon tired of it for this very reason, as people once tired of the "glass harmonica" which was a lively fad in the days of Benjamin Franklin, but which exhibited this same unfortunate characteristic.[11]

The Telharmonium, though a masterpiece of early electrical ingenuity, was a financial disaster and eventually faded into obscurity. Even though the Telharmonium was not a commercial success, due to the ingenuity and the completeness of its design, Cahill should be considered the greatest of the early electrical music pioneers. He should be credited with developing the general principles which have been used in rotating-wheel electronic musical instruments built after his Telharmonium, including the Rangertone and the highly successful Hammond Organ.

A very early instrument which utilized the tone wheel principle was the Choralcelo, patented in 1906 by Melvin Severy and George B. Sinclair. The Choralcelo was a hybrid instrument which had both electromechanical and acoustical components. Periodic electrical currents of various frequencies were generated using small rheotomes that interrupted electrical circuits. These pulsations were conveyed to electromagnets placed near the striking point of piano strings, causing the strings to resonate. A given string would resonate loudly if the electrical pulsation applied corresponded closely to the frequency to which the string was tuned.

Because the Choracelo used acoustical resonators, electrical requirements were modest. Hence, the instrument could be a great deal smaller than the Cahill Telharmonium. The working parts of the instrument were housed in a large case resembling an upright piano, and the instrument could be played from a keyboard, manually, utilizing ordinary percussion hammers, or electrically, by keying the electromagnets, or in both modes simultaneously.

The Choralcelo made its first public appearance in Boston, 1909, sharing the program with the Boston Symphony Orchestra.[12] Little is known about the Choralcelo's subsequent history. In 1936, B. F. Miessner wrote:

> The Choralcelo reached commercial exploitation and production, in some quantities, about twenty years ago. Its chief difficulty appears to have resided in inability to maintain accurate resonance between thousands of tuned mechanico-acoustic vibrators and their periodic, magnetic driving forces, provided by rotational current interrupters and electromagnets. As a result these instruments were very difficult to keep in tune, not because of frequency variations sufficient to impair temperament, but because of serious upsets in dynamic and timbre voicing through inexact resonance.[13]

With the exception of Duddell's Singing Arc, the earliest electrical musical instruments were necessarily electro-mechanical devices. Not until DeForest and others perfected the necessary technology would true "electronic" musical instruments appear--instruments whose electrical oscillations are produced wholly by electrical components.

FOOTNOTES FOR CHAPTER I

[1]"Twain at the Telharmonium," Electrical World, XLVIII, No. 26 (December 29, 1906), 1233.

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[5]J. Murray Barbour, "Music and Electricity," Papers, American Musicological Society (Pittsburgh, Pa., 1937), p. 1.

[6]Ernst Lorenz, German Patent 33507 (March 12, 1885).

[7]Thaddeus Cahill, U.S. Patent 580,035 (1897); 1,107,261 (1914); 1,213,803 (1917); 1,213,804 (1917); 1,295,691 (1919).

[8]Thaddeus Cahill, "Electrical Music as a Medium of Expression," Proceedings, Music Teachers National Association (Hartford, Conn., 1907), p. 207.

[9]Ray Stannard Baker, "New Music For an Old World," McClure's Magazine, XXVII (July, 1906), pp. 293-94.

[10]"The First Public Telharmonic Concert," Electrical World, XLVIII, No. 14 (October 6, 1906), 637.

[11]Edwin Hall Pierce, "A Colossal Experiment in 'Just Intonation'," The Musical Quarterly, X, No. 3 (July, 1924), 331-32.

[12]"Another Electrical Triumph in the Musical World," Scientific American Supplement, LXVII, No. 1743 (May 29, 1909), 351.

[13]Benjamin F. Miessner, "Electronic Music and Instruments," Proceedings of the Institute of Radio Engineers, XXIV, No. 11 (November, 1936), 1429.

CHAPTER II

MONOPHONIC INSTRUMENTS

While many useful principles of electrical musical instrument construction were discovered by the early experimenters, the development of practical instruments became possible only after the development of technology in apparently unrelated fields.

The most important development was the invention of the radio "valve," or tube. This device made possible the development of circuits capable of producing undamped oscillations, and provided the foundation for modern amplification principles.

Thomas Alva Edison is credited with constructing the prototype of the radio tube in 1883 while experimenting with incandescent lamps. His immediate concern was preventing the carbon-filament lamp from becoming darkened with use by a thin layer of carbon. Edison constructed several special types of bulb fitted with a small metal plate opposite the filament inside the evacuated bulb. The plate was connected to a wire sealed into the glass wall of the bulb, so the plate could be electrically charged. Edison discovered that if he gave the plate inside the tube a positive charge, a current would flow continuously onto that plate. (Electrons flowing from the glowing filament were attracted by the plate which had a positive potential, i.e., a deficiency of electrons.) He further discovered that a negative charge on the plate stopped the flow of current inside the bulb. This phenomenon became known as the "Edison effect."

Edison paid little attention to this discovery, since it did not solve the immediate problem of constructing a usable incandescent light bulb. Neither Edison nor his contemporaries realized the immense future that awaited this simple two-element bulb.

In 1884 Edison described his experiments and exhibited these special bulbs and their curious features. The exhibit was seen by Ambrose Fleming, a British physicist, who made a useful application of the Edison effect with his invention, in 1904, of the radio "valve," or tube. Fleming's device, which we now call a "diode tube," was useful as a detector of radio waves, acting as a rectifier of the feeble oscillating waves in a receiver aerial. It converted the oscillating movements of the radio waves into a succession of pulses of current in one direction. This current could be used to drive a telephone receiver or speaker. The mode of operation was quite simple. Fleming applied the oscillating radio waves received by the aerial to the plate of the valve. When the electrons rushed one way in the aerial, they created a negative charge on the plate and stopped the flow of current in the valve; conversely, when the electrons flowed the other way in the aerial, a positive charge was produced on the plate, allowing current to flow through the valve. An oscillating current produced by radio waves received in an aerial was therefore converted, in the valve, into a succession of pulses of current flowing in one direction. When the radio waves were weak, the electron flow in the valve was proportionately weaker. This continuous variation in the strength of the radio waves, which formed the message pattern, was reproduced by the valve as a corresponding pattern of variation in the strength of current flowing through the valve. This current, when applied to a telephone receiver, would create air-vibrations similar to those which originally struck the microphone at the radio transmitter.

Fleming's invention greatly facilitated the development of radio and stimulated research in many countries. In 1906, two years after Fleming had patented his "radio valve," Lee de Forest introduced in the United States a modified type of valve which he called the "audion." The importance of this development cannot be overestimated. The audion was much more sensitive than the Fleming valve and could be used for amplifying the feeble aerial oscillations of radio waves into currents of enormous strength. This valve, which is the prototype of today's triode tube, consisted of a Fleming valve with a third component, a grid of metal wire fitted between the filament and the plate. This grid acted like a sluice-gate to control the flow of electrons between filament and plate. Because the grid was placed close to the filament, a small electrical potential place on the grid had a much larger effect on the electrical field within the valve, and therefore on the plate current, than would the same potential placed on the plate itself. De Forest utilized this capability of his audion valve to amplify radio waves. He applied the oscillating radio waves not to the plate, as with the Fleming valve, but to the grid, which <u>controlled</u> a much higher current flowing from filament to plate. Hence, oscillations applied to the grid resulted in similar oscillations of much greater amplitude at the plate. This principle of amplification of weak oscillations made possible the improvement or development of most of the electronics industry of today, including the production of electronic musical instruments. For the sake of convenience, the author will adopt the more modern terminology, calling the Fleming and de Forest devices "tubes," and referring to the musical instruments which use these devices not as "electrical," but "electronic" musical instruments.

As indicated in the preceding chapter, William Duddell was probably the first to produce an instrument which created tones by purely electrical means. Duddell's direct-current arc had a shunt circuit containing an inductance (coil) and a capacitor. This kind of circuit was used in many later instruments, and is now referred to as a "tank circuit," or "L-C circuit"--L for inductance, C for capacitance. Such a circuit is capable of producing damped oscillations, or oscillations of decreasing amplitude, through the action of the discharge of the capacitor through the inductance. When the capacitor discharges, it causes current to flow through the coil. The coil, in turn, creates rings of magnetic force. When the capacitor has discharged completely, there is a reversal in current direction produced as the magnetic field falls back into the coil. This recharges the capacitor. When the magnetic field around the coil has collapsed, the capacitor discharges again, repeating the cycle. This arrangement produces a sine wave whose frequency is determined by the inductance to capacitance ratio, which dictates the time it takes for the current to flow from the capacitor through the coil and back to full charge again. The oscillations will not continue forever, but will die out since the resistance in the circuit consumes a small amount of energy during each cycle. Consequently, simple circuits which create only these damped oscillations are not extremely useful in the construction of oscillators for electronic musical instruments. However, it was found that undamped or continuous oscillations could be produced if one fed back into the tank circuit a small amount of current at the right time using an amplifier. This became known as "regenerative feedback." De Forest's triode tube provided the necessary means of amplifying feeble oscillations and made regenerative feedback possible, thereby facilitating the production of undamped oscillations.

It should be noted, however, that it is not impossible to build an instrument which uses damped oscillations. Joseph Bethenod, of Paris, designed his Electric Piano Harp[1] about 1928, making use of acoustic coupling, or feedback to sustain the oscillations in a tank circuit. In this rather impractical design, a microphone was placed in proximity to a speaker in order that the very feeble damped oscillations could be acoustically regenerated and controlled by the feedback circuit. In 1915, an American, Frank Ebenezer Miller, described the more practical Electrical System for Producing Musical Tones,[2] which utilized damped oscillations produced in an L-C circuit. The fundamental challenge in such a design is to make the oscillations continuous. Miller solved this problem by using an alternator, which supplied the necessary current to provide regenerative feedback in the tank circuit. He derived a musical scale by empirically selecting different ratios of inductance to capacitance in the individual tank circuits for each note. He keyed these circuits with a large revolving drum which had electrical contact points located at appropriate places, much as a player piano. The output of the tank circuits was amplified by a triode tube. Oddly enough, it did not occur to Miller that he could have eliminated the alternator in his scheme if he had merely fed back a portion of the amplified damped oscillations to the tank circuit from the plate of the triode tube, thereby making the oscillations continuous.

Later in 1915, Lee de Forest lodged the first patent application for an oscillator which made use of this principle of regenerative feedback from the plate of the triode tube.[3] De Forest's design included a grid-filament circuit consisting of a coil and a variable capacitor, constituting a tank circuit. An associated plate-filament circuit used a "tickler" coil to provide regenerative feedback in the tank circuit, creating undamped oscillations. The oscillator could be keyed by using switches which introduced one of several high resistance leak paths connected between the grid and filament electrodes in the triode tube. The pitch produced depended on the amount of resistance in the leak path, the inductance values in the circuits, and the values of the various capacitors. In the patent specifications de Forest indicated that the simplest way to produce a scale was to graduate the resistance of the leak paths by making heavier or lighter marks with a graphite pencil used to form the resistances. Heavily marked, or low resistance paths, produced higher pitches than did high resistance paths. De Forest also indicated that by gradually varying the capacitor in the tank circuit, a siren note of continuous pitch could be obtained. In a magazine article he further stated:

> The pitch of the notes is very easily regulated by changing the capacity or the inductance in the circuits, which can be easily effected by a sliding contact or simply by turning the knob of the condenser. In fact, the pitch of the notes can be changed by merely putting the finger on certain parts of the circuit or even *by holding the hand close to parts of the circuit*. In this way very weird and beautiful effects can be easily obtained.[4] (Italics mine.)

This implies that de Forest anticipated the popular hand capacitance instruments of Leo Theremin by some years, though there is no record that de Forest used the principle to build a workable instrument. De Forest was certainly aware of the beat-frequency or "heterodyning" principle used in the Theremin instruments, however. He described the principle in another article:

> At a later date when developing the Audion amplifier as a relay for telephone currents and weak wireless signals, I found that with two bulbs connected in cascade this Ultraudion condition could be more readily produced, due to the tendency of the impulses set up in the second Audion to react upon the first, through the coupling transformer or associated circuits.
>
> In fact, the low or audio frequency oscillations thus set up often became a nuisance until special care was taken to neutralize this reactive tendency. Loud siren notes, of pure quality and piercing intensity, were readily obtainable, the pitch of which could be altered in droll effects merely by touching one or another point of the associated circuits with the finger.
>
> . . . .
>
> The pitch of this note can be run through the entire gamut of audibility from upper audibility down to a low guttural note, then lapsing into inaudibility as the two oscillating circuits are brought into nearly exact resonance, then rising higher and higher as one or the other circuit is again detuned.[5]

De Forest found, after some experimentation, that the timbre of the tone produced could be altered, creating imitations of various instruments and ". . . other sounds, which while pleasing to the ear were quite unlike those emitted from any musical instrument with which we are familiar."[6]

De Forest built a rudimentary instrument which used one triode tube for each octave, with an arrangement of keys and switches allowing production of any single tone in that octave. The output of the triode tubes was made common to a set of speakers which could be grouped in one place, or distributed in different parts of the room, giving a spatial dimension to the sound. De Forest was very excited about his discovery of the "music of the lamps." He wrote:

> In all my work with the audion--and I can imagine no device in the whole realm of physics of greater fascination than this little audion principle--I have never found any phase of its unlimited possibilities quite so interesting as this of producing musical notes. In the next twelve months I hope to be able to produce an instrument which will be far enough perfected so that I can turn it over to musicians to work out the thousand and one details of musical perfection which such men alone are capable of introducing.[7]

In December of 1915, de Forest described the Audion Piano,[8] a device that made use of the principles which he had discovered. It is uncertain whether the instrument was successfully completed, due to difficulties in the construction of enough efficient and stable triode tubes.

De Forest's role in the development of electronic musical instruments is a central one. He described circuitry and developed principles which are the bases of several later instruments, using both audio and radio frequency designs. The invention of the de Forest audion made possible the design of oscillators and amplifiers necessary for the production of practical electronic musical instruments.

Many of the early monophonic instruments were constructed using the radio frequency design reported by Lee de Forest in 1915. This design featured two high frequency oscillators that interacted with each other to produce an audible "beat frequency," or "difference tone." Instruments having tone generators of this design became known as "heterodyning" instruments, a term borrowed from the radio industry.

Some of the earliest heterodyning electronic musical instruments to attract attention were those of the German teacher and organist, Joerg Mager. Mager's earliest instrument, the Electrophone, was completed around 1921. It used two oscillators in the fifty kilohertz range. An improved version with filter chains to control timbre, renamed the Sphaerophon, was demonstrated in private performances a few years later. This instrument had a crank or handle which was attached to the variable capacitor of one of the oscillators used to derive the audible beat note. Turning the crank varied the capacity, and hence the frequency, of that oscillator, causing a beat note to be heard. The beat note varied throughout the range of hearing without discrete steps. A half-circle placed under the crank had marks indicating the chromatic scale, improving pitch accuracy in performance. Even so, musically disturbing glissandi were still present.

Mager tried to eliminate this problem in his next version of the Spaerophon by installing a second crank. By using this crank one could "preselect" the following note. Mager presented this instrument in July, 1926, at the music festival of Donaueschingen in the Zeppelin Hall. The instrument was hardly noticed in the program devoted to mechanical music, with works by Paul Hindemith, Ernst Toch, and Gerhard Munch. Only Georgy Rimski-Korsakov, the grandson of the famous Russian composer, wrote a few quarter-tone exercises for the Spaerophon.

Mager thereafter abandoned both the heterodyning design and the "stepless space" concept, with its inherent sliding pitches. His later instruments employed audio frequency generators keyed by changes in capacitance, using keyboard manuals and a pedal. The first of these, the Klaviatur-Spaerophon, was constructed with the support of the German Radio Office, the Heinrich Hertz Institute, and the German Telegraph-Technical Office. This instrument had two monophonic keyboards and a monophonic pedal. In 1929, the city of Darmstadt placed a building in the city park, as well as technical helpers, at Mager's disposal for a concert with the new instrument. But Mager became suspicious of the offer, and refused, for he zealously guarded against any attempt on the part of others to plagiarize his work in order to mass-produce the instrument.

In 1930 he introduced another of these instruments which was neither strictly monophonic nor truly polyphonic. Mager played Bach, Beethoven, Wagner, and Mendelssohn on this three-manual Klaviatur-Spaerophon. He also composed a highly romantic "Christmas Cradle Song" for the instrument, in which the different timbre of each voice was produced by resonators and specially shaped speakers. In Frederick Prieberg's book Musica ex Machina we find a description of this instrument taken from a newspaper review:

> Mager produced today an organ with many registers on which four-voice playing is possible. So far there is only one difficulty; that is, that each voice must have its own keyboard, thus the four voice movement must be played on three manuals and the pedal. For this reason the manuals must be so close to each other and the keys so short, so that one can easily play on several manuals with one hand. For this reason the keys are somewhat narrower than those on a regular organ or piano keyboard. Apart from these difficulties, which require a special adjustment to the playing of the new instrument, it is surprising in its infinite multiplicity of sound possibilities, through the dynamic wealth of shading, and through the possibilities of expression in the tunes.[9]

Soon after this, Mager increased the instrument to five voices and called it the Partiturophone.

Mager enjoyed much greater success with these keyboard instruments than with his previous variable-pitch instruments. Musicians and technicians came to Darmstadt full of intellectual curiosity and praise for his new instruments. Winifred Wagner visited him in 1931, and requested that he come to Bayreuth in order to imitate electronically the bells in Parsifal. Mager was very successful in this venture, using Javanese gongs in an electrical bell-music device. While at Bayreuth he played his five-voice Partiturophone for interested persons such as Arturo Toscanini and Wilhelm Furtwaengler.

In 1932 Mager worked with Gustav Martung at Faust performances in Darmstadt and Frankfurt, on the occasion of the centennial commemoration of Goethe's death. Concerning the music for these performances Mager said:

> In the prologue, the sun is accompanied by music with ethereal vibrato. The growling of the poodle is underlaid with microtonal sounds. In the Night of the Witches' Sabbath there is spooky, demoniacal, eccentric music. The howling of the monkeys is represented using strongly vibrating metal membranes. Witches' and devils' sounds are mixed into a sound whirl of tone trills.[10]

Political conditions in Germany after 1933 severely restricted further work by Mager. His productivity was limited to the production of a portion of the film score for the film Stronger Than Paragraphs (1936), and the construction of an obscure instrument after the timbre ideals of Schoenberg and Busoni, the Kaleidophon. This instrument, which was said to mix tones "kaleidoscopically," was destroyed, along with all of Mager's other instruments during World War II.[11]

Mager died in 1939, unable to accomplish his mystical and idealistic goals of an electronic music for the masses: an electronic sound beneficially influencing body and soul. Earlier he had written:

> With the technical means of radio something much higher and powerful could be achieved, namely to place at the disposal of music the totality of all additional tones on which the timbre depends. With this totality a new world of sounds can be created which can overshadow all that has been achieved until now. . . .[12]

Mager's dreams never materialized. His instruments, in particular, attracted little attention outside of Germany.

In dramatic contrast, the heterodyning instruments of the Russian physicist Leo Ssergejewitsch Theremin created interest on an international scale. This was probably due to the visual interest inherent in the playing technique of his most famous instrument, the Thereminvox, or Aetherphon. This instrument, often called simply the Theremin, had two antennae which controlled pitch and loudness. The performer could play the Theremin by merely waving his hands in the electromagnetic fields produced by these antennae. No physical contact with the instrument was necessary.

Leo Theremin invented many electronic musical instruments which used the heterodyning principle, but this space-controlled instrument, the Aetherphon (Theremin), was his most radical and significant contribution. He said of it:

> I visualize great possibilities in connection with the problem of controlling sound material by means other than mechanical, by the free movement of the hands in the air, which offer more intimate connection of these sounds with the individuality of the performing artist, and make available not only the expressive power of existing instruments, but perhaps even greater possibilities.
>
> For this purpose an invention had to be found, I have introduced a method of controlling sounds and their nuances (pitch, volume, character, etc.) by the free movement of hands in space.
>
> . . . .
>
> I have reason to believe that I was the first to propose and develop the method; the product of which I have named--to distinguish it from the product of the contact or keyboard method--"ether music."[13]

Leo Theremin is said to have developed his Aetherphon in Russia before 1920, while he was a student at the University of Petrograd.[14] In 1920 he introduced this instrument to an electrical congress in Russia, astounding and outraging some of the participants. The first Theremin used two high frequency sine-wave generators, at about three hundred kilohertz, to produce an almost pure beat note. One of the generators remained at the established frequency, while the other generator was made to vary in frequency by the addition of "body capacitance" as the hand was brought into the electromagnetic field of the pitch antenna. The volume was controlled by a variable resistor connected to a foot pedal.

Claims of prior invention of ether music were made by, or in behalf of, several other inventors when Leo Theremin began to concertize with his device late in 1927. Several writers credited Joseph A. Givelet, of France, with concurrent invention of the principle. Dr. Frank E. Miller of New York claimed that Theremin's ether music was a variation of his Electrical System for Producing Tones, discussed earlier in this chapter. Claims such as these arose from authors holding too narrow a perspective about electronic musical instruments. During this time, many writers thought of all electronic instruments as roughly equivalent, regardless of their mode of operation. Hence, audio frequency and heterodyning designs were often confused or equated.

As previously shown, Dr. Miller's circuits did not create undamped oscillations, nor did they use the heterodyning method. Little is known about the Givelet keyboard instrument which was demonstrated in France in 1928. Givelet and Edouard E. Coupleaux later specialized in building polyphonic instruments using hundreds of tubes.

At any rate, Leo Theremin's contribution of hand control seems to be the most important feature of his instrument. Only Mager's Spaerophon could, at this time, approximate the musical effect brought about by this unusual playing interface.

While there was, at first, much opposition to the concept of ether music, eventually composers began to experiment with the new instrument. The first composer to use the new instrument was Andrej Fillipowitsch Paschtschenko, a student of Maximilian Steinburg, Director of the music library of the Leningrad Philharmonic. He wrote "A Symphonic Mystery" for Theremin and orchestra, which was premiered in May of 1924 by the Leningrad Philharmonic, W. Dranischnikow conducting.[15]

Ernst Toch wrote after one of the first performances in Germany of Theremin's instrument:

> I personally have tried for many years to increase the register of the orchestra in a clear, definite direction. . . .
>
> In Theremin's instrument much of what I have visualized, has been realized: and beyond that, unimagined possibilities of new sounds.[16]

The young inventor sought to protect his invention with patents, making application to the German patent office December 8, 1924, and applying for U.S. patent on December of the next year. The U.S. patent contains descriptions of several advanced designs for instruments of the space-controlled variety.[17] Theremin's patent specifies means of controlling not only the pitch, but also the volume and timbre of the sounds. While many variations are detailed, the following gives the essential details of his preferred designs.

The oscillators employed for the beat frequency system were of the order of five hundred kilohertz, the precise frequency chosen so as to avoid intereference with radio broadcast reception. Each high frequency oscillator, rather than the low frequency beat note, was amplified separately to avoid undue distortion of the beat tones. The connection of the antennae used in pitch control could be made either to the grid or anode circuit.

Volume could be controlled in a variety of ways. One of the simplest means was to place an adjustable resistance in the circuit with the speaker, using a foot pedal for control. The method which became most popular used a circuit similar to the circuit producing pitch. The volume control had a control circuit and an oscillator circuit which could be made to vary in capacitance through hand position in proximity to an antenna. The circuits were constructed in such a way that maximum energy and, hence, amplification would be generated when the control circuit and oscillator circuit were in resonance. As with the pitch circuitry, adjustment could be made so resonance occurred when the hand was either nearest to, or altogether removed from the antenna.

The basic wave shape produced by the Theremin was fairly simple because the radio frequency oscillators produced near-sinusoidal waves. The sound has often been described as similar to that of a human voice on the syllable "ooh." Leo Theremin points out several methods of timbre control. In his U.S. patent he stated:

> The variation of the quantitative composition of the overtones in the sound or musical tones may be effected by various deformations of the primary alternating current, by utilizing the curved parts of the amplifier characteristics.
>
> The composition of the overtones may also be varied by increasing or reducing the overtones of the higher order by inserting oscillating elements comprising capacitances and inductances of suitable values.[18]

Leo Theremin built an instrument using some of these designs and embarked on an international concertizing tour, introducing the instrument in Frankfort, Germany. The occasion was the exposition "Music in the Life of the People," on August 4, 1927.[19] This instrument was housed in a small mahogany box, the pitch control metal rod of about fifteen inches length rising vertically from the right. At the left, the volume control, a rod bent into a ring, extended horizontally. Reaction at both the Frankfort concert and a concert in Berlin the next month was wildly enthusiastic. Spectators were incredulous that music could be made by merely waving one's hands. One reporter remarked that Professor Theremin ". . . had but to twiddle his little finger to vary pitch and amplitude."[20] Theremin himself made some rather extravagant comments:

> My apparatus frees the composer from the despotism of the twelve-note tempered piano scale, to which even violinists must adapt themselves. The composer can now construct a scale of the intervals desired. He can have intervals of thirteenths, if he wants them. In fact, any gradation detectable by the human ear can be produced.[21]

Ironically, this ability of the instrument to produce "any gradation" of pitch was later recognized to be the instrument's most serious weakness, being a persistent source of poor intonation.

Theremin's success in Germany propelled him to a whirlwind tour of such European capitals as London and Paris, where he demonstrated ether music at the Salle Gaveaux and the Paris Opera. Police were called to keep order among the crowds which thronged to the Opera performance. For the first time in history, standing room was sold in the boxes.[22]

On December 21, 1927, Leo Theremin arrived in New York City to demonstrate his instrument to musicians and scientists. The first American concert was presented January 24, 1928, in the Grand Ballroom of New York's Hotel Plaza.[23] This debut was a private concert presented under the auspices of such notables as Walter Damrosch, the Vincent Astors, the Edsel Fords, the Fritz Kreislers, and many others. Guests present for the concert included Sergei Rachmaninoff, Arturo Toscanini, and Joseph Szigeti. The program included a lecture by Professor Theremin entitled "A New Way of Producing Music." Musical selections included Schubert's "Ave Maria"; the "Swan," by Saint-Saens; Offenbach's "Musette"; a Scriabin etude; and others. The instrument was hailed as an important and exciting addition to the musical world. Everyone was impressed at the ease with which the "ethereal" sounds were produced.

The first <u>public</u> demonstration of the Theremin was given at the Metropolitan Opera House on January 31, 1928.[24] The program was substantially the same as that of the concert given earlier at the Hotel Plaza. The evening after the Metropolitan Opera House concert, Professor Theremin demonstrated his ether music at the home of Cornelius Vanderbilt for a reception and dance in his honor.

Leo Theremin and his assistant, Jeorg Goldberg, subsequently appeared in several public concerts in New York City, playing solos and duets accompanied by Kurt Ruhtseitz at the piano.

Theremin made his orchestral debut with the New York Philharmonic Symphony Orchestra on August 27, 1928.[25] He was assisted by three of his students who had been trained in the playing of ether-wave instruments. The instruments were voiced to produce the ranges and approximate the timbres of a string quartet. Musical selections accompanied by the orchestra included "Vocalise," by Rachmaninoff (one instrument); "Ave Verum," by Mozart (two instruments); "The Swan," by Saint-Saens (four instruments); "Largo," by Handel (four instruments); and Liszt's "Hungarian Rhapsody No. 1," played by Professor Theremin. The performance of the new ether music was followed by ". . . five minutes of persistent applause that brought the rather constrained young Russian back for a half dozen bows."[26]

While public and critical reaction to these concerts was generally favorable, some consistent defects in the new instrument were noted. Because of the space-controlled mode of operating the instrument, good intonation was difficult to maintain. Rapid passages, especially those requiring staccato were also extremely difficult. These problems made the selection of music of a variety of moods and tempi difficult, often resulting in monotonous concerts of slow-moving cantilenas and arias. The Theremin was, however, acknowledged to be an extremely effective instrument for slow legato passages because of its capability for sensitive vibrato and glissando control.

In an effort to expand the capabilities of ether-wave instruments which utilized the heterodyning principle, Leo Theremin developed several instruments which had more conventional playing controls. One of these instruments used a keyboard that controlled the amount of capacitance connected into the variable oscillator circuit. This keyboard version of the Theremin merely provided a fixed scale system in place of the variable space-controlled method. The instrument was monophonic, since only one beat note could be derived from the two oscillators. Volume was controlled by a foot pedal. The keyboard Theremin remedied the deficiencies of the space-controlled model, but lacked vibrato and glissando control.

In some concerts, both instruments were used in a complementary fashion along with another of Theremin's ether wave instruments, the electric cello. This one-stringed instrument resembled a cello with a greatly reduced resonating cavity. The performer controlled the pitch by depressing the string at appropriate points. A lever worked by the right hand controlled the volume. Leopold Stokowski used this electric cello with the Philadelphia Orchestra to augment bass lines in a transcription of Debussy's "Engulfed Cathedral."[27]

Maestro Stowkowski has been a persistent innovator in the use of electronic musical instruments. He worked for some time with Leo Theremin in discussing the development of instruments of various tessituras which might be used as new voices in the orchestra.

In September of 1929, the Radio Corporation of America announced plans to manufacture Theremin's space-controlled ether music device. The public was assured that anyone who could hum or whistle was likely to play the RCA Theremin as well as a trained musician. Leo Theremin appeared at the Radio Fair in New York, September 25, to promote the sale of the RCA Theremin. The concert, which included Chopin's "Etude, Opus 10, No. 3," and Rubinstein's "Romance," was the radio debut of the instrument.[28] The program was broadcast coast-to-coast by station WJZ.

Within months, Theremin appeared on the concert stage with the New York Philharmonic Symphony Orchestra and the Cleveland Symphony Orchestra to perform Joseph Schillinger's "First Airphonic Suite" for the RCA Theremin. Reviews were generally unfavorable. Ether music was, by this time, no longer a novelty, but was being judged on its own merits. Olin Downes reported that the Schillinger Suite was:

> . . . a simple and rather sentimental ditty . . . sung by the solo instrument and developed in a well-constructed score by the orchestra. The composition is not important per se, though it is well enough written. It adheres to fairly well-known harmonic formulae, and is evidently constructed with a special eye to simplicity and a background for a sustained melody to be played on the electrical antennae.[29]

In fairness, it should be pointed out that Mr. Downes held a very conservative attitude concerning electronic musical instruments, as evidenced by his further comments:

> We do not like to think of a populace at the mercy of this fearfully magnified and potent tone that Professor Theremin has brought into the world. The radio machines are bad enough, but what will happen to the auditory nerves in a land where super-Theremin machines can hurl a jazz ditty through the atmosphere with such horribly magnificent sonorities that they could deaden the sound of an automobile exhaust from twenty miles away?[30]

Another reviewer blasted the instrument for its lack of precision in brutally slurring all intervals, equating the sounds produced to those of an inferior cello sloppily played.

He went on to say that, in the finale of the Schillinger Suite the Theremin ". . . sounded like a horridly soaring female voice."[31]

Joseph Schillinger and Leo Theremin collaborated on a concert given at Carnegie Hall in April of 1930 to highlight "developments for 1929-1930."[32] The developments included the introduction of an "orchestra" of fourteen space-controlled Theremins which employed added radio-frequency circuits designed to produce additional overtones for new timbres. The newer fingerboard Theremin (electric cello) was played by the composer Wallingford Riegger, who had had only ten days to master the new instrument. Other significant developments included the addition of a color wheel to accompany the ether music. The program was accompanied by Arle Abileah on piano and Stephano Di Stephano on harp.

Professor Theremin's ether wave piano and cello were presented in their radio debut by the "Electrio," consisting of George Goreff, Leonid Bolotine, and Vladimir Brenner, in June, 1931. The program of popular dance tunes was accompanied by the staff musicians of radio station WJZ. The timbres of the instruments were described in a newspaper article:

> All three of the instruments are said to have wide musical range and exceptional bass notes. The space control instrument has a timbre similar to that of the human voice, but of a much wider range. The fingerboard instrument's tone resembles the strings of the orchestra, while that of the keyboard instrument varies widely and cannot be compared to any one instrument, but produces an effect like the piano, one of its tones closely resembles that of the English horn.[33]

The most ambitious and varied Theremin concert given in this country was presented under the direction of Albert Stroessel in March, 1932, at Carnegie Hall. The Theremin Electrical Symphony consisted of a total of sixteen fingerboard and keyboard instruments. Also presented for the first time were the Theremin Ether Wave Musical Dance Stage and the Keyboard Electronic Tympani, both using the familiar heterodyning principle. The Dance Stage, or Terpsitone, consisted of a platform which was responsive to the movements of a dancer, translating various steps and postures into sounds. Waving the arms governed the pitch, and stooping or rising, the volume.[34] Miss Clara Reisenberg is said to have performed the Bach-Gounod "Ave Maria" by dancing on this instrument.[35]

The Cowell-Theremin Rhythmicon, built to specifications of Henry Cowell to produce extremely complex rhythmic patterns was also presented at this recital. The nucleus of this instrument was a photoelectric cell, toward which light impulses were steered by keyboard. The light was interrupted by various rotating cog-wheels which produced both the pitch and divided it into various rhythms. Cowell wrote two compositions for the Rhythmicon that year: a four movement "Rhythmicana" with orchestra, utilizing many poly-rhythms; and "Music for Violin and Rhythmicon."

Theremin was apparently sensitive to the visual element in the concert environment, for he supplied several large rotating disks having geometric patterns and Arabic numerals which were made to fluctuate. The effect was created by a U-shaped neon tube used as a stroboscopic light in conjunction with one of the Theremins. As the pitch changed, the neon light flickered periodically, causing the geometric designs and numerals on the disks to appear to jump and change due to the visual phenomenon of "persistence of vision." This was more than an entertaining curiosity, for discrepancies in intonation could be observed by watching the numbered disks.

Leo Theremin attracted many devotees during his stay in America. Several individuals became deeply involved with his space-controlled instrument, giving solo recitals of ether music. Among these was Clara Rockmore, who gave recitals beginning around 1934, with a Town Hall recital. This program consisted of slow-moving pieces entirely, including a

Bach Arioso and adapted compositions of Marcello, Ravel, Goldmark, Lalo, and others. In 1945 she premiered the Concerto for Etherphone and Orchestra, by Anis Fuleihan, with the New York City Symphony, conducted by Leopold Stowkowski.

The most faithful adherent of the art of ether music was the Theremin soloist, Lucy Bigelow Rosen. Mrs. Rosen not only became the leading advocate of the Theremin, but she also donated a considerable amount of money to support Leo Theremin's experiments in his New York laboratory. Mrs. Rosen's career as Theremin soloist spanned some twenty years, beginning in the Thirties, and continuing into the Fifties. She became the most persistent defender of the aesthetic possibilities of the instrument. In a 1934 letter to the editor of the New York Times she stated:

> . . . the Theremin . . . reflects accurately the whole nervous and emotional system behind the hands that play on it, more sensitive to the musician's hands than any other instrument, and for this reason capable of a profounder variation in tone color.[36]

Lucy B. Rosen played a number of recitals during the following decade, usually accompanied by Frank Chatterton on the piano. The availability of a virtuoso players of the Theremin such as Mrs. Rosen probably played a role in alerting composers to the possibilities of the instrument. Indeed, many works were written specifically for Lucy B. Rosen's frequent recitals.

Some examples of literature written for this instrument are: "Equatorial," for two Theremins, by Edgar Varese (1934); "Concerto in F, for Theremin and Orchestra," by Mortimer Browning (c. 1939); "Serenade," for Theremin and piano, by John Hausserman, Jr. (1944); "Fantasia," for Theremin, piano, and String quartet, by Bohuslav Martinu (1944); "Improvisation," for Theremin with piano, by Isidor Achron (1945); "Passacaglia for Theremin and Orchestra," by Nicolai Berezowsky (1947); "Improvisata," for Etherphone and string quartet, by John Haussermann (1950). More recently, Lejaren Hiller has used the Theremin in his "Computer Cantata."

In April of 1940 Mrs. Rosen embarked on her third concert tour of Europe to play the Theremin in London, The Hague, Zurich, Geneva, Rome, Venice, Vienna, and other cities on the Continent. Her heavy schedule of engagements was undertaken somewhat in the spirit of a crusade to proselytize in behalf of the Theremin. Before departing for Europe she stated:

> More people should know the Theremin. And how can they, unless someone goes out and plays it for them? I would like musicians, especially composers, to realize that the Theremin welcomes new works and that its players are constantly seeking new compositions, particularly those written for the instrument. It has passed through the stages

> of try outs, of being a collector's item or an entertaining hobby. With development in reliability and control, the Theremin has attained an artistry level which commands respect.[37]

During 1952-1953 she made concert tours in the Southern United States, through Georgia, Florida, and South Carolina.

Despite these efforts, the Theremin has not become an extremely popular instrument with "legitimate" composers. The instrument has, however, enjoyed a great deal of popularity as a novelty instrument in motion picture scores, especially for suspense and science-fiction films. One of the first Theremin performers in Hollywood was Dr. Samuel Hoffman, a Chiropodist, who had become acquainted with the Theremin while living in New York. Hoffman, a violinist, began to play Theremin with the Jolly Coburn band around New York as a novel "double." When he moved to Hollywood he was approached by Miklos Rozsa to play the Theremin in the score for Spellbound. Hoffman said of this meeting:

> He (Rozsa) came out to see me with a sketch of the part he wanted to write and was delighted when he discovered I could sight-read it. So the Theremin part went in the Spellbound score; the score won an Academy Award.[38]

This success stimulated the use of the Theremin in several other films, including The Lost Weekend, The Red House, and Walt Disney's Alice in Wonderland. While these were not the first films in which the Theremin was used, the instrument was so successful that it became quite fashionable in movie scores after 1945.[39]

During this period of renewed popularity of the Theremin, Robert A. Moog of Moog Synthesizer fame founded a company to build the Theremin. During this time, Mr. Walter Sear, now a Moog Synthesizer representative, played the Moog Theremin for various functions around New York City.

The Theremin has had the most remarkable tenure of popularity of any electronic musical instrument. The instrument has been "rediscovered" several times and been utilized in various ways, as an electronic orchestral instrument, solo instrument, and sound effects novelty instrument. Perhaps the most telling sign of its early popularity was in its number of imitators.

In 1927 Erich Zitzmann-Zirini built the Electronic Violin, which used the space-controlled method of pitch control employed in the Theremin. Zitzmann-Zirini controlled keying and volume through a "selector" connected by means of cable to the box housing the instrument. Zitzmann-Zirini recognized early the novelty aspect of the Theremin and used his imitation to produce musical comedy for radio, television, circus, and the stage.

In 1929 Martin Taubman constructed his battery-powered <u>Electronde</u> in Berlin, adding a dynamic pedal and a keying switch to be activated by the left hand to Theremin's design. Taubmann gave a recital on the Electronde in 1933 before the Golders Green and Hendon Radio and Scientific Society in England.

This recital and an earlier appearance by Leo Theremin stimulated G. G. Blake, an Englishman, to build his <u>Ethonium</u>, another heterodyning instrument which offered no improvement over Taubmann's or Zitzmann-Zirini's devices. Blake's expertise in this matter came from an earlier scientific experiment with a heterodyne method used to measure the infinitesimally small changes in capacity due to the movements of the aluminum leaf of a radiometric condenser. Blake's interest in electronic music was evidently primarily restricted to possible scientific applications, such as the study of hearing impediments. He made little use of the Ethonium for strictly musical purposes.

In 1932 the Heinrich Hertz Institute introduced an apparatus based on Theremin's ideas designed for "home" use. The instrument (unnamed) consisted of a small box with a single antenna which controlled pitch, a button for keying, and a foot pedal for volume control. The Institute arranged to have several of these instruments placed in sound-proof rooms at the Berlin Wireless Exhibition so that visitors could learn to play them.

Several Theremin-like instruments appeared in France. The Ondium Pechadre (1930) used a variable condenser actuated by the right hand to control pitch, and a key to control volume. The instrument attracted little attention.

One of the more unusual heterodyning instruments introduced in France was La Croix Sonore, or "The Sounding Cross." The instrument was built by the Russian exile Nicholai Obuchow in collaboration with the Princess Marie Antoinette Aussenac-Broglie, the engineer Michel Billaudot, and Abbe Douilly. The instrument appeared as a cross standing on a globe, a form having religious significance. Ouchow fled Russia during the Revolution and settled in Paris under the name of Nicholas Obouhoff. He was an extremely mystical composer, marking his scores with his own blood to signify the blood spilled in the Revolution, and attaching great significance to musical keys. Obouhoff built the Sounding Cross around 1934 and installed it in a bizarre apartment on the eighth floor of a house in Paris. Originally, he allowed only the "initiated," or elite of society to see and hear the curious instrument, which stood approximately five feet tall.

In February, 1934 the instrument was presented to the public for the first time in Brussels. In May, Obouhoff presented portions of his huge work Book of Life, and "Annunciation of the Last Judgment," accompanied by the Sounding Cross. A reviewer of the Paris concert commented:

> . . . it was the instrument which had the most success. . . . out of it, by moving her hand back and forth, the Princess de Broglie drew an amazing sweetness or the most dreadful note, like the knocking of fate, to give to Obouhoff's strange religious music far more power. . . .[40]

Little was heard of the Sounding Cross in later years.

The most important heterodyning instrument developed in France and introduced in 1928 was the Ondes Musicales, or Ondes Martenot. This instrument, often called simply the Martenot, employed the familiar high-frequency generators used in other instruments, but offered a different arrangement for control of pitch. Early designs featured a wire and pulley arrangement attached either to a variable capacitor, variable resistor, or variable inductance.[41] By adjusting the appropriate component, capacity, resistance, or inductance in the circuit could be varied, thereby altering the pitch. In early versions Maurice Martenot chose to vary the capacitance in the tone-generating circuit, using an endless wire or band on pulleys to rotate a variable capacitor.[42] A small celluloid ring was attached to this band, allowing the performer a means of moving the band, and ultimately, the variable capacitor. The forefinger of the right hand was placed in the celluloid ring to accomplish this. To facilitate location of dicrete pitches a painted "dummy" keyboard was placed under the path of the pitch-controlling band and celluloid ring. By placing the finger at appropriate points along this keyboard any gradation of pitch could be produced.

The instrument was keyed by the left hand which controlled a small button. This button, when fully released produced a silence, and when fully depressed, a fortissimo tone. The left hand also controlled three "stops" which, in combination, gave a choice of eight tone qualities, and one other which controlled the "envelope," or attack.[43] Timbre was controlled by switching on filter circuits which acted upon harmonics (up to the twelfth) produced in the first stage of the amplifier.

Later improvements of the Martenot included the addition of more timbre stops and an acoustic resonator to improve tone quality; introduction of a true keyboard, facilitating a second non-legato mode of playing;[44] and the introduction of a more sophisticated capacitance control system for the original pulley-controlled variable-pitch mode of operation.[45]

Many models with the new keyboard (five or seven octaves) had a unique arrangement whereby the performer could supply vibrato by shaking the keyboard, causing periodic changes of capacitance in the tone circuit.[46] The new variable-pitch scheme involved the use of a movable metallic ribbon which acted as the variable plate of a capacitor having air as the dielectric. The stationary plates of the capacitor were arranged on either side oblique to the ribbon, converging on it. When the metallic portion of the ribbon was moved into this funnel-like arrangement, the converging stationary plates, in effect, became "closer" to the variable plate (the ribbon) of the capacitor, altering the capacitance in the circuit. Through several of these stationary plates, suitably modified with fixed capacitors, the entire range of the instrument was controlled.

Maurice Martenot introduced the Ondes Martenot at the Paris Opera in April, 1928, approximately one year after Leo Theremin had amazed Parisiens with his Etherphone.[47] The Ondes Martenot, like the Theremin, was an immediate success. The inventor was asked to give a special performance for the President of the French Republic at the Elysee Palace on May 18, 1928.[48]

After a European tour, Martenot arrived in the U.S. to demonstrate his "Instrument of Musical Waves." The first concert in this country was given December 12, 1930, with the Philadelphia Orchestra under the direction of Leopold Stowkowski.[49] The program included a sarabande and courante by Buxtehude, several other transcribed works, and a symphonic poem written for the Martenot by Dimitri Levidis. On December 16, Martenot appeared with the Philadelphia Orchestra in a Carnegie Hall concert. The new ether wave instrument was generally acclaimed to be musically superior to Theremin's Etherphone. One reviewer said:

> The tones were not always agreeable; but they lacked the distressing portamento that marred the performances of Professor Theremin, and they had far more flexibility of utterance.
>
> . . . .
>
> Apparently the principle governing both devices is the same; but Monsieur Martenot uses a different kind of apparatus, and, what is much more important, gets different and better musical results from it. He has eliminated certain of the earlier crudities and defects that marred this "music from the ether." He has not only tamed the "howl," he has taught it politer musical manners.[50]

In January of 1931 the Martenot was played over WABC's network in its American radio debut. The program included "The Swan," by Saint-Saens, performed by Maurice Martenot accompanied by pianists Ginnette Martenot (his sister) and Alexander Sammier; "Tambourin," by Rameau; and Greig's "Anitra's Dance" from <u>Peer Gynt Suite No. 1</u>, with symphony orchestra.

Following his appearance in America, Maurice Martenot embarked on a world tour, including the Orient. During this time he played the Martenot for the Indian poet Rabindranath Tagore, who was astonished at the possibilities the instrument offered Oriental composers who did not use the Western octave division. On the pote's instigation, with the assistance of the musicologist Alain Danielou, a special microtonal instrument was built in 1938 to reproduce the minute nuances of pitch found in Hindu music.[51]

Over five hundred works have been written which use the Ondes Martenot.[52] They are both orchestral and chamber works, including ensembles for trios or quartets of Martenots. Some composers who have written for the instrument are Oliver Messiaen, Darius Milhaud, Dimitri Levidis, Arthur Honegger, Florent Schmitt, Jacques Ibert, Andre Jolivet, Jean Martinon, Maurice Jarre, Edgar Varese, and many others.[53]

The Ondes Martenot has become particularly popular in France. A Martenot orchestra of eight instruments appeared on stage in a Paris Exposition Concert in 1937, performing several works with ". . . none of the seesawing glissando business that characterized certain earlier efforts in the ethereal field, but a precision of attack and a purity of style that any orchestra might covet."[54] The instrument is still used in radio and television, and especially for stage music at the Opera Nationale, the Opera Comique, the Comedie Francaise, the Theatre National Populaire du Palais de Chaillot, and the Folies-Bergere.[55]

In this country the instrument has been used for film music and music for jingles and commercials. Raymond Scott, composer and inventor, and Eric Siday, New York composer, pioneered the use of the Ondes Martenot, as well as other electronic musical instruments, in such commercial applications. For instance, the aural "logo" now heard over the American Broadcasting Company television network was created by Eric Siday, using the Ondes Martenot.[56]

While the Ondes Martenot quickly became, considering the number of works written, the world's most popular electronic musical instrument, several instruments introduced in France during the same time did not fare so well. In the years 1927 and 1928 Armand Givelet demonstrated several keyboard instruments using various tuning systems. The instruments faded into obscurity, though Givelet is credited with being the first to experiment with the recording of electronic sounds.[57]

In 1928, the engineer Rene Bertrand presented his Dynaphone, which employed a multivibrator having a variable capacitor to control pitch. Later models featured a keyboard of five octaves, having the capability of sounding the fifth and octave simultaneously with the tone played.[58] A few compositions were written for the Dynaphone, including Ernest Fromaigeat's "Characteristic Variations" for six Dynaphones and Arthur Honegger's "Metal Roses" for three Dynaphones and piano.

An instrument which amounted to little more than a curiosity was the Boreau Radiotone (c. 1930). The instrument employed a string in tension between a fixed support and the armature of a telephone receiver. The string was "bowed" by a revolving wheel, thereby inducing currents in the receiver coils. Pitch was controlled by varying the length of the vibrating string, volume by a pedal actuating a resistance in the amplifier circuit, and timbre by filter circuits. The Radiotone had little impact on the musical world.

Concurrent with the popularity of instruments which used the heterodyning principle, there arose, especially in Germany, another method for tone generation. In this method a relaxation oscillator[59] was created by a neon tube used in a circuit with a capacitor and a resistor. Frequency could be altered by changing the value of the capacitor or the resistance. Unlike the capacitance-controlled heterodyning instruments, a number of instruments using the neon tube, or gas-discharge tube oscillator, were constructed with variable resistance schemes for pitch control. Examples of such instruments are the Trautonium, the Emicon, the Emiriton, and the Oscillion.

Several of these instruments used fretboard-like band manuals instead of keyboards for pitch control. An earlier instrument having this feature was built in Germany by Bruno Helberger and Peter Lertes, in the winter of 1928-1929.[60] The instrument was called the Hellertion, a word formed from the two names of the inventors. While the Hellertion did not have a gas-discharge oscillator, from a viewpoint of performance controls it appears to be the archetype for the Emiriton and the more-important Trautonium.

The Hellertion had an audio frequency generator with a simple feedback circuit. The schematic shows a bias resistor; a potentiometer is connected in series between the cathode, the grid of a triode tube, and the secondary of a transformer/capacitor circuit.[61] By altering the amount of resistance with the potentiometer the amount of bias voltage connected to the grid may be controlled. This grid bias controls the amount of current flowing through the primary transformer, thereby changing the inductance of both primary and secondary windings. This change of inductance influences the frequency of oscillations produced by the plate-grid circuit which is connected through the transformer. A pitch range of four or five octaves can be produced.

The mode of altering the resistance is of particular interest, since it established a model which was imitated by several instrument designers. A metal band insulated with leather on the upper side was stretched over a resistor consisting of a wire-wound bar which was convex on its upper side. The performer depressed the metal band to make contact with the resistor at various points, altering the resistance and causing a change in pitch. This very useful design allowed a good deal of flexibility in control of articulation of musical phrases. Furthermore, the attack could be controlled by a contact mechanically connected to the resistor. When the metal band was depressed into the resistor, it caused the resistor to mechanically vary the proximity of two coils. This influenced the coupling between the anode circuit of the oscillating tube and the grid circuit of the amplifying tube, varying the amplification.

Even though the Hellertion's capabilities were expanded with the addition of several tone bands, allowing performance in several voices, the instrument never had much significance musically. The Hellertion was introduced at the Munich

Congress on Electrical Music in 1931, but did not receive a public hearing until 1936, when it was presented at the Festival Auditorium of Frankfurt-on-Main.[62] Helberger later developed a unique instrument called the Heliphon, about which little is known. Its claim to fame appears to be that it was composed of over seventeen thousand separate components.[63]

Although the Hellertion did not become popular, it is important, for it provided the keying concept used in another German instrument, the Trautonium. The Trautonium, developed by Friedrich Trautwein in 1928, was a gas-discharge tube instrument. The audio frequency generator produced a sawtooth wave, extremely rich in upper partials. In the original design, these oscillations were created in a neon tube connected in parallel with a capacitor.[64] When current, after passing through a resistance, charged the capacitor to a given value, the charge would be dissipated through the neon tube and a small series resistor. Then the voltage across the capacitor would fall to a low value at which the neon tube would no longer act as a conductor. This cycle was repeated, producing a sawtooth wave at the neon tube, and a series of pulses at the small associated resistor, which were applied to the grid of an amplifying triode tube.

The frequency with which this cycle occurred was dependent upon the circuit values and the characteristics of the neon tube.

The waveform produced was further modified by an arrangement of two or more resonant transformer circuits found in the plate circuit of the triode. The periodic pulses across the small resistor were used to excite damped oscillations in these resonant circuits, so that the output voltage waveform was not simply an amplified replica of the input waveform being applied to the grid (sawtooth). Furthermore, the plate voltage was not derived from a fixed-potential point, but from the function of the resistance/capacitance circuits which fluctuated in sawtooth waveform, resulting in an even more complex sound output.

In later versions, the neon tube was replaced by the more stable gas triode, or thyratron.[65] Another circuit possibility was the application of the fingerboard resistance to the grid of a triode tube, allowing the tube to act as a control for the charging of the neon (or thyratron) tube. This arrangement improves the linearity of the fingerboard, presenting higher octaves from becoming unnecessarily cramped.[66]

The fingerboard, or tone band, used to key the

Trautonium was similar to, but more sophisticated than, that of the Hellertion.[67] The biasing resistor which controlled pitch was wound around an elliptical rod approximately one yard long. This rod was surrounded by a resilient metallic gauze which could be depressed to make contact with the resistor, altering the pitch. Dummy keys served to indicate major pitch divisions, such as the octaves and fifths. In early models, amplitude was controlled by foot pedal, and there was no further provision for envelope control.[68] This caused the early instrument to have a monotonously harsh attack, a defect pointed out by several writers.[69] To rectify this fault, Trautwein supplied a tube with liquid resistance (mercury) placed under the pitch-controlling rod. When the liquid resistance was depressed gently, a less explosive attack was formed, transforming the Trautonium into a pressure-sensitive instrument.

The tone band was not the only keying control that Trautwein envisioned.[70] In order to provide a more familiar interface to the Trautonium for wind players, he considered a tube-shaped "manual" that was to be held like a woodwind. The resistance wire controlling pitch was to be coiled around this cylinder. A rubber balloon connected to a carbon rheostat was to be provided for the regulation of the volume of the tone. The player would then manage the pitch with his fingers while blowing into the "play tube" more or less strongly to control the volume. The idea was never implemented.

The Trautonium had remarkable capabilities for the production of unusual timbres. Trautwein's design for timbre alteration evolved from his complex theory of the existence of hallformanten, or "tone-formers," which account for the timbre of acoustical instruments. His theory differs from the older Helmholtz explanation of timbre as the relative strength of overtones. Although tone-formers were always higher than the fundamental note, as in the overtone theory, they were not necessarily multiples of the fundamental.

Trautwein supplied the electrical equivalent of tone-formers in the Trautonium with resonant circuits that could be tuned over a wide range. Since the Trautonium had a number of these circuits in different octaves of the instrument, the timbre could be made to change with the tessitura, much like a wind instrument. The tone-former construction was an extremely important development, for now the composer or performer was not limited to a discrete number of timbre "stops," as on many other electronic musical instruments, but had at his disposal hundreds of timbres. This feature probably attracted many composers, and partially explains the popularity of the Trautonium.

The Trautonium has been built in two versions: one built by the Telefunken Company as a simple single manual instrument with a few formant filters, and the other by Trautwein's young co-worker, Oscar Sala, as a more elaborate two manual version.

The Trautonium was introduced in 1930 at the Radio Research Section of the Berlin Academy of Music.[71] Trautwein spoke of his goals in an interview:

> While electro-acoustics has dealt in the last few years primarily with problems of reproduction, I wish to prepare for the creative artist new possibilities of expression. Mechanical music has not enriched art as such, but only enlarged it in respect to the former case. I, however, believe that I am serving creative art through my work before all and, therefore, contributing to the reconciliation of the two branches of the human mind which have erroneously been placed in opposition to each other: art and technology.[72]

Trautwein was fortunate to have colleagues such as Paul Hindemith and Harald Genzmer who took an interest in the new instrument. Hindemith not only composed for the Trautonium, but also became a proficient performer on the instrument.

Some of the early compositions for the Trautonium include Hindemith's "Essays in Three-Part Polyphonic Compositions" for three monophonic Trautoniums (1930, Berlin); Kretzmer's "Two and Three-Part Compositions for Trautonium" (1930, Berlin); and Hindemith's "Concertino for Trautonium and String Orchestra," which was premiered at the Second Convention for Radio Music in Munich, 1931.

In 1932 the firm Telefunken began to mass-produce an improved model of the Trautonium with a gas-filled triode instead of the original neon tube. The Telefunken Trautonium created a great deal of interest at the Berlin Radio Exhibition of the same year; it was the first electronic musical instrument to be mass-produced by an industrial firm.[73]

Oscar Sala soon made a reputation for himself as the first virtuoso of the new instrument, stimulating various composers to write for the Trautonium. Literature for the instrument includes Paul Hoffer's "Little Chamber Music for Electric Instruments" (1932); Harald Genzmer's _Concerto for Trautonium and Winds_ (1936), and _Concerto for Trautonium and Orchestra_ (1937), and "Suites for Trautonium and Piano" (1938, 1940); Oscar Sala's "Suite for Solo Trautonium" (1937); Wolfgang Friebe's "Capriccio for a Range of Six Octaves for Trautonium and Piano" (1940); Georg Haentzschel's "Intermezzo for Trautonium and Orchestra" (1940); a rhapsody by Hermann Ambrosius; Fried Walter's "Elegy and Humoreske," for Trautonium and orchestra (1941); and Klaus Jangk's "Music for Trautonium and String Quarter" (1951).[74]

Like many other electronic musical instruments, the Trautonium has been used for "sound effects" in musical works, in films, and on the stage. Richard Strauss made use of the Trautonium to imitate the sounds of gongs in his "Japanese Festival Music" (1940). The instrument was used to create a demoniacal atmosphere of Hades at the Berlin premiere of Werner Egk's ballet Abraxas. Paul Dessau made use of the Trautonium in his music to Faust (1949), and in his opera The Trial of Lucullus (1951).[75]

In 1952 the founders of the electronic music studio of Cologne commissioned Trautwein to design an electronic sound producer similar in design to the Trautonium. This instrument, the Trautwein Electronic Monochord, was somewhat simpler than the Telefunken Concert Trautonium since it was not to be used in a real-time performance situation. Trautwein described the Monochord in this way:

> The electronic monochord in Cologne corresponds approximately to the revious version, the concert Trautonium, which had been obtained in 1936 by the Reichsrundfunkgesellschaft (German Broadcasting Company) from Telefunken and which was installed in the Berlin Radio Station, where it was used in numerous broadcasts up to 1945. However, in the new version subharmonic tones and the means of changing the register with the aid of lateral pedal motions were omitted for the reasons explained above.[76]

Prior to this Oscar Sala had begun making design alterations and further contributions which would lead to a much-expanded instrument based on Trautwein's ideas. This instrument, the Mixture-Trautonium, was never completely finished, for Sala had many ideas which increased the musical abilities of the instrument.[77] Besides expanding the basic circuitry of the older concert model to include many more tone-formers, Sala added a white-noise generator, a circuit breaker for rhythmic effects, a reverberation unit, and frequency dividers to provide subharmonics. At first, Sala used the Mixture-Trautonium as he had used the older Trautonium--as a real-time concert instrument. Composers also wrote concert works for the Mixture-Trautonium, such as a concerto for the instrument with orchestra without woodwinds, by Harald Genzmer (1952); and a concerto for Trautonium and string quartet, by Jurg Baur (1956).

Sala soon realized, however, that he could use the new instrument not only as a performance instrument, but, in conjunction with the tape recorder, as an entire sound-producing studio. From a historical viewpoint, this was an important revelation, for it signaled the emerging awareness of some of the concepts which have led to modern "Synthesizers." This event marks the transition from the production and use of solely performance-oriented electronic musical instruments to the emergence of studio-oriented instruments specifically designed to be used with the tape recorder. Although Sala began to use the new tape medium, he remained essentially conservative, tending toward a luxurious late romanticism.[78] Representative works include his "Concertino for Mixture-Trautonium and Electric Orchestra" (1953); and "A Night in Electronia" (1955). The Mixture-Trautonium has also been used by Sala and others in film, television, and ballet scores.[79]

On March 22, 1961, the New York City Ballet presented Electronics, a ballet choreographed by George Balanchine to an electronic work by Remi Gassman, assisted by Oscar Sala.[80] The score was realized entirely on the Mixture-Trautonium. Gassman's comments indicate his awareness of the unique position the Trautonium held as an electronic musical instrument. He said:

> The Studio Trautonium, as designed and developed by Oskar Sala, made it possible to use this particular electronic instrument as an exclusive source of basic musical sound. Besides, its recent development incorporates the complete resources of the electronic sound studio as well. Hence, in this work, electronic sound, the virtuoso possibilities of the electronic instrument and the further manipulations and techniques of the electronic sound studio, are for the first time inextricably bound together.[81]

The pitch control scheme used in the Trautonium has been used in several other instruments. In 1937 Dr. William Francis Gray Swann and Dr. William E. Danforth of the Franklin Institute's Bartol Research Foundation collaborated to build the Oscillion. Swann and Danforth were quick to point out that ". . . none of the principles used in the new instrument are new to electrical science, ...[82] The Oscillion was a gas-discharge, resistance-controlled instrument, similar in principle to the Trautonium. Certain features of design, however, were unique. The instrument was housed in an oblong wooden box about twelve by three by three inches. The performer held the Oscillion on his left arm and keyed the instrument with his right hand by depressing the resistance strip on top. The left hand was used to manipulate buttons that controlled the pitch range of the resistance strip, and also to control the volume with a small lever.[83] The Oscillion was built to "pinchhit" for instruments missing from the Swarthmore Symphony Orchestra, Swarthmore, Pennsylvania. Swann was the conductor of this small volunteer group, and Danforth was normally a cellist when not playing the Oscillion. The instrument made its world debut in May, 1937, playing the passages in Cesar Franck's D Minor Symphony.[84] Little was heard of it after that.

In 1944, Alexander Antipovitch Ivanov and Andrei Vladmirovitch Rimsky-Korsakov (grandson of the composer) collaborated to "invent" the Emiriton, an obvious copy of the early Trautonium.[85] The instrument had its debut at the Moscow Conservatory the same year. According to one reporter the performers included Ivanov and ". . . a tall man who never seemed to move or be moved, two girls of about 17 who swayed ecstatically with their work and two nervous young men who looked as if they ought to stop fooling around with Emiritons and get out and play football."[86] When the concert of Russian music was over, the announcer said there would be a short discussion on the Emiriton. "All but eight of the 1,600 music lovers promptly swooshed out into the night."[87]

Another sliding-pitch instrument with circuitry similar to the Trautonium was introduced in the United States in 1951. L. A. Meacham's Wobble Organ consisted of a thyratron sawtooth oscillator, with simple wave-shaping circuits, having a range of about two and one-half octaves.[88] The tone circuit was the same as the Trautonium except that the pitch was controlled by resistance at the anode, not the grid of the tube.[89] This variable anode resistor was attached to the main control device, the "wobble arm," a stick for pitch control. The wobble arm was moved over the face of a quadrant control which facilitated finding discrete pitches. Keying was accomplished with a button connected to a circuit designed to avoid harsh transients.[90] The instrument was not intended for commercial production.

Not all neon tube, (or thyratron), instruments had continuous-pitch playing controls. Several instruments used keyboards. One such instrument introduced in the United States was the Emicon, a gas-discharge, resistance-controlled instrument developed by Nicholas Langer. The Emicon was introduced in 1932 by Pratt-Read and Co., Deep River, Connecticut, and was distributed by M. I. Conn, Inc., New York.[91] In physical appearance the Emicon resembled a small spinet or harpsichord. It had a true keyboard of thirty-two keys which made contact with a series of resistors of the proper value to produce the proper pitch. Tone quality was controlled by a system of filters. No details concerning enveloping have been discovered, although volume control is said to be at the disposal of the player.[92] The Emicon had little effect on music in the United States, but is of some historical interest, for it is one of the first gas-discharge, resistance-controlled instruments having a keyboard.

In 1951 Richard H. Dorf introduced his Thyratone, a three octave keyboard instrument complete with wave shaping circuits, tone generators synchronized over three octaves for additional timbre control, and an electronic vibrato circuit. Full details for the construction of this thyratron instrument are found in parts IX and X of Dorf's excellent series, "Electronics and Music," found in Radio-Electronics.[93]

While the early inventors of monophonic electronic musical instruments experimented with unorthodox playing controls for their instruments, there was a tendency, after 1940, toward universal adoption of the keyboard for commercially-produced instruments.[94] Manufacturers of instruments during this time concentrated on the problems of producing instruments which would stay in tune, sound pleasant, and be easy to play.[95] An instrument introduced in the United States which fulfilled these requirements was Laurens Hammond's Solovox, a monophonic instrument having thirty-six keys. The Solovox was designed as an adjunct to the piano and was meant to be played with it.[96] The Solovox used a single vacuum-tube oscillator in the highest octave, made to vary in frequency from 2093 to 3951 hertz.[97] By pressing a given key, from the lowest note "c" to the highest note "b," a certain amount of capacitance was inserted into the grid circuit of the oscillator, tuning the oscillator to the appropriate frequency. Lower octaves of the instrument were obtained by a cascade of frequency dividers. Each frequency divider used three triodes to divide the input frequency in half, producing a note one octave lower than its input note.[98] On the front of the instrument are a group of rocking tablets with which one controlled the various octaves produced by the frequency dividers. Tablets marked Soprano, Contralto, Tenor, and Bass provided the means of playing a given note in several octaves. Other tablets were for timbre control and attack characteristic. Timbre was controlled in several ways.[99] By connecting a diode tube which was shunted across each divider, the output would include both even and odd harmonics; by switching the shunt circuit off, the even harmonics were suppressed, resulting in a hollow clarinet-like sound. Also, a group of resonant circuits (filters) were provided in the output circuit of the preamplifier, Envelopes were controlled by attack tablets which switched in capacitors of different value. Volume was controlled by a knee lever. In the older models "J" and "K," vibrato was supplied by a vibrating reed which modulated the main tuning coil in the pitch oscillator. Later models used a totally electronic vibrato circuit.[100]

The Solovox was introduced in 1940 by Dr. Frank Black, music director of N.B.C., on the Cities Service program.[101]

Many people thought that the Solovox would have a stimulating effect on the piano industry. Dr. Fritz Reiner was very interested in the instrument, as evidenced by his comments:

> Laurens Hammond's new instrument, the Solovox, is not only an outstanding technical contribution to the number of electrical instruments but also a musical one. Its endless possibilities for creating new and fascinating sound effects in combination with the piano, will kindle the imagination of every pianist. In fact, the Solovox, may revitalize the present style of writing for the piano.[102]

Reiner's enthusiastic prediction did not come to pass, but the instrument did have a significant impact on the popular music field, finding its place in "combos" of various sizes. The instrument is rarely seen today.

Another instrument which appeared in this country was the Clavioline, an invention of the Frenchman M. Constant Martin. In appearance and mode of operation, the Clavioline was very similar to the Hammond Solovox. The Clavioline had a three octave clavier, eighteen stop tablets for tonal effects, three vibrato speeds, two vibrato amplitudes, a percussive-effects tablet, and a knee lever for volume control.[103] It lacked, however, the Solovox's capacity for octave coupling. The Clavioline made use of a set of thirty-six tuning resistors in order to cover the compass of the instrument. In addition, the instrument could be tuned either up or down an octave, thus creating a playing range of five octaves. Timbre was controlled with a set of resonant, high and low-pass filters. The Clavioline was used much as the Solovox, as an adjunct to the piano. The tones simulating strings and brass were said to be very realistic.[104]

Another very similar instrument was the Ondioline, built in 1941 by Georges Jenny, and produced by the French firm La Musique Electronique.[105]

A British instrument of this design is the Univox, described in British patent 722,430.[106] This three octave instrument uses a vacuum-tube oscillator which produces a sawtooth wave. In this oscillator, the capacitor of the circuit is charged extremely rapidly and discharged slowly, in contrast to the more usual practice of performing the converse operation.[107] Three vibrato speeds, between four and eight cycles per second, are available. Timbre control is effected of switching in combinations of fifteen tone-forming circuits. Volume is controlled by the ubiquitous knee lever. The instrument utilizes double touch contacts under the keys so that attack can be controlled by keyboard touch.[108] The pitch range of the Univox, like the Solovox, is extended by frequency division.

A curious instrument which uses the Univox tone-generating circuit is the Hohner Multimonika. This hybrid instrument resembles a two manual accordian, having a lower manual that is wind-blown, and an upper manual that is electronic. Different frequencies are obtained by gradually reducing the value of capacitance shunted across the tuning circuit.[109]

The Hohner Company also builds a version of an instrument with design characteristics similar to the Solovox and Clavioline. The Electronium Pi is reported to have a six octave range with twenty tilt-keys for vibrato, attack, and timbre control.[110] This instrument was used in Hans Brehme's Symphony Number 2 (1950), and his "Six Sound Pictures for Three Electrons and Piano"; in Helmut Degen's Concerto, with orchestra (1954); and Wolfgang Jacobi's "Music for Four Electrons" (1954).[111]

The monophonic electronic musical instrument has had a long and colorful history. Many instruments have been introduced which offer new compositional possibilities. Lamentably, often the new instruments have been used merely to simulate acoustical instruments and perform extant musical literature. Hugh LeCaine observed:

> . . . the important orchestral combinations, both large and small, will still be found to consist almost exclusively of instruments invented more than seventy-five years ago, and we are forced to conclude that the problem of producing an electronic monophonic instrument to supplement or replace the conventional monophonic instruments is still unsolved.[112]

FOOTNOTES FOR CHAPTER II

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[28]"Radio Fair to Hear 'Theremin' Tonight," N.Y. Times, Sept. 25, 1929, p. 28:4.

[29]Olin Downes, "Music," N.Y. Times, Dec. 4, p. 36:2.

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CHAPTER III

POLYPHONIC INSTRUMENTS

Unlike monophonic electronic instruments, polyphonic instruments have become very popular. These instruments have created new musical styles and have replaced acoustical instruments in some situations. The acceptance of the electronic organ, piano, and guitar in popular music is evident. In many cases the pipe organ has been replaced by the smaller, more economical electronic organ.

It is not obvious why polyphonic electronic instruments have enjoyed such great success while most monophonic electronic instruments have disappeared. Both types often offer advantages over their acoustical counterparts, such as greater portability, wider dynamic range, easier maintenance, increased tonal possibilities, and often less cost. The question arises--why have polyphonic instruments been so successful, while monophonic electronic instruments have largely failed? Polyphonic electronic musical instruments enjoy greater popularity because: (1) They provide better imitations of their acoustical counterparts than do monophonic electronic instruments. The enveloping and nuance capabilities of traditional polyphonic instruments are less subtle than traditional monophonic instruments. This simplifies requirements for electronic imitation. (2) Traditional playing technique transfers easily to polyphonic electronic instruments. In contrast, many monophonic electronic instruments had difficult or obtuse playing controls which demanded a new technique. (3) Often, electronic substitutes for traditional polyphonic instruments offer greater savings than do substitutes for traditional monophonic instruments. (4) Polyphonic electronic instruments fulfill an established musical function. Many of the monophonic electronic instruments were experimental, hence the high failure rate.

The history of monophonic electronic instruments is intimately related to the invention and improvement of electron tubes. Almost all of the early monophonic instruments used triode tubes or neon glow-tubes as integral parts of their tone generating circuits. In contrast, few early polyphonic instruments used tube oscillators. This was probably due to the expense, lack of uniformity, and instability of tubes manufactured prior to World War II. In 1938, Benjamin F. Miessner wrote:

> The chief difficulty with both audio oscillator and neon tube generators is pitch instability. With many hundreds of such oscillators in an organ it becomes almost impossible to keep them in tune. Pipe organs experience some difficulty of this type but to no such degree.[1]

Although several early polyphonic instruments were built using tube oscillators, it soon became apparent that electromechanical oscillator systems would be more practical. A great variety of such designs proliferated.

Due to improvements in the electronics industry, most electronic organs are now totally electronic. Hence, the development of polyphonic instruments has occurred in two major phases; the early period was devoted almost wholly to electromechanical devices, and the latter period is devoted to purely electronic devices. The author will discuss the electromechanical instruments in detail. Discussion of the totally electronic instruments will be limited to the early examples, since there is a great deal of literature available elsewhere on contemporary designs. Sources of information about contemporary instruments will be cited at the close of this chapter.

S. K. Lewer has stated a useful rationale for the classification of electronic musical instruments:

> Since the developments in electronic music have come mostly from the electrical side rather than from the musical side, it seems logical to make the primary distinctions on an electrical basis.[2]

This author has adapted the following outline from Lewer[3] to guide the discussion of the various types of polyphonic instruments:

I. ELECTROMECHANICAL GENERATORS
   A. Vibratory
      1. Microphone Pickup
      2. Photoelectric
      3. Electromagnetic
      4. Electrostatic
   B. Rotary
      1. Photoelectric
      2. Electromagnetic
      3. Electrostatic

II. ELECTRICAL CIRCUIT GENERATORS
   A. Vacuum Tube Oscillators
      1. Sinusoidal Oscillators
      2. Complex Waveform Oscillators
   B. Gas Discharge Tube Oscillators
      1. Complex Waveform Oscillators
      2. Sinusoidal Oscillators

The earliest electrical instrument with electromechanical vibratory generators was constructed by Ernst Lorenz in 1884.[4] This instrument used the principle of self-maintained vibration found in electric buzzers. Since that time many inventors have used various vibratory designs to produce musical tones. The fundamental idea is the translation of mechanical or acoustical vibrations into electrical oscillations that can be amplified and modified by electrical circuits.

This discussion will not describe exhaustively the many design possibilities for vibratory instruments. B. F. Miessner, an authority of instruments of this type, gives an indication of the possibilities:

> In the vibrating types we have many forms of mechanical vibrators such as strings, reeds, rods in transverse and longitudinal vibration, bells, plates, and membranes, with mechanico-electric pickup. We also have direct acoustic types of whatever nature with microphonic pickup, amplification and reproduction. Also we have many hybrid types, such as mechanical vibrators maintained by self-interrupter, or feed back, or magnetostriction methods, or beat oscillations between mechanico-electric and electric oscillators.
>
> Even this extended list makes no pretense at completeness.[5]

There are also many ways of exciting the vibrating medium, and translating mechanical vibrations into electrical oscillations. Miessner lists several:

> There are available a variety of exciting methods for strings. Among the mechanical types are percussion, plucking and bowing. Or it may be excited impulsively, or continuously by electromagnetic, electrodynamic or electrostatic means, at any desired point, or at several points simultaneously. The continuous excitation may be synchronous, or non-synchronous, in which case the effects of bowed strings may be produced. Its vibration may be initiated or maintained by electromagnetic or other feed-back methods.
>
> . . . .

> For transforming the mechanical vibration of our strings into electrical oscillations of corresponding form, we may make use of a number of principles, such as modulation of a magnetic or an electrostatic field, of steady or radio frequency types; or the string's change in tension or pressure on its supports may be used to modulate resistance, piezoelectric, or magnetostrictive device s .[6]

The author will discuss designs which have been used to make complete musical instruments.

The simplest vibratory design is the use of a contact microphone with an acoustical instrument. Often this amounts merely to amplifying the instrument. As Oskar Vierling pointed out:

> After amplifier and microphone were developed so that the sound of instruments could be satisfactorily produced over microphone and amplifier, the thought was immediately obvious to provide musical instruments with such arrangements. F. C. Hammond was the first to put this idea into practice and thus establish a new direction in the development of the electrical musical instrument.[7]

Numerous inventors have experimented with this design, including B. F. Miessner,[8] F. C. Hammond,[9] Hugo Gernsback,[10] E. Hoffman,[11], F. W. Dierdorf,[12] W. Harden,[13] B. Bizos,[14] Oskar Vierling,[15] R. F. Starzl,[16] Fred W. Roehm,[17] and Ivan Ivanovitch Eremeeff.[18] These designs use a microphone that works not through acoustic energy, but through the mechanical motion of the body of the acoustical instrument. A. Zouckermann, however, built an instrument which used sound waves directly.[19] In most cases these designs did not create radically new instruments, but merely provided amplification for existing instruments.

Photoelectric vibratory designs are rare. However, Richard H. Ranger built an instrument which used photoelectric translation of wind-blown reeds.[20] The reeds operated continuously, and small lights operated by the keyboard furnished light which was modulated by the reeds and reflected into a photocell. This method did not become popular in the design of vibratory electronic instruments.

In the electromagnetic method, a permanent magnet or an electromagnet is placed close to a stretched steel string (as in a piano or guitar), causing the string to become magnetized. A coil with a soft iron pole is also mounted near the string. When the string vibrates at a given frequency, it induces a voltage of corresponding frequency across the coil. This voltage may be translated into sound with an amplifier and speaker.

The electrostatic design is a popular method of great versatility. This is the method generally used in electronic pianos and electronic vibrating reed organs.[21] In this type, a screw or other small conducting object is mounted near a string (or reed) which is to be set in vibration.

The screw and string form the plates of a small capacitor. A polarizing voltage is applied to each screw through a filter network. As the string vibrates, the capacitance formed between the string and screw varies. This varying capacitance is translated into a varying voltage that can be amplified and translated into sound.

Several hybrid vibratory devices have been suggested. R. Eisemann patented a device in 1913 that used a contact microphone on a string instrument soundboard. The microphone fed back currents to driver electromagnets. The electromagnets were used to maintain string vibration in another mechanico-acoustic instrument.[22] In 1918 Sewall Cabot filed to patent his Synthetic Tone Musical Instrument,[23] which used rotating tone wheels to create electric currents. The currents were used to drive metallic resonator bars. These bars were fitted with additional electromagnetic pickups from which sound was eventually derived.

The most fruitful designs for vibratory instruments, especially electronic pianos, have been the electromagnetic and electrostatic types. In these cases the pickup is electrical, i.e., the vibrating medium is not in contact with the pickup. Electrical oscillations are created in the pickup by the motion of the vibrating generator. Instruments of this type usually employ reed or string generators that are wind-blown or percussively excited.

The application of electricity to the piano seems to be the logical extension of several earlier attempts to alter the expressive capabilities of the instrument. Several factors are probably responsible for the zeitgeist that called for experimentation with the piano. Sales of pianos slumped by fifty per cent during the years 1913-1921.[24] Several writers forecast a gloomy future unless something could be done to rejuvenate public interest in the instrument. Margaret Anderton wrote in The Musician:

> The time has come, and has now ripened, for some further improvements in our well-beloved instrument. The whole scheme of the pianoforte is on the brink of great changes.
>
> Both manufacturers of this popular instrument, and artists and players upon it, have for some time been realizing the need for certain improvements.[25]

Beryl Rubinstein, concert pianist, implied that the compositional possibilities for the piano might be exhausted. He wrote:

> I am not an inventor and I cannot presume to say just what directions new ideas of piano playing or manufacturing will take We seem to have traveled the full length of the road so far opened. We have scanned the scenery thoroughly. We must have a new horizon, otherwise we shall look no more, and not looking we will cease to think. There remains then stagnation.[26]

Some blamed the decline of the piano industry on the growing popularity of the phonograph and radio:

> It seems that the pianoforte is passing away. . . . A few years ago the music shops were full of songs and piano and violin music; now they devote their space to gramophone disks and jazz records. Piano teachers complain that they have fewer pupils.[27]

Several inventors offered modifications of the piano which were intended to create new expressive effects. In 1921, Emmanuel Moor introduced his two-manual octave-coupled piano in England. With Moor's piano it was possible to attain four-foot and sixteen-foot tones (like a harpsichord) equal in strength with, and of the same quality as the tone of the single keyboard piano. The Moor piano generated some enthusiasm at first, but eventually faded into obscurity.

In 1925, a more successful piano was introduced in this country by John Hays Hammond, Jr. Hammond's Breathing Piano used a series of pivoting slats mounted above and below the conventional piano's soundboard. The object was to control the release of acoustical energy from the soundboard. The following describes Hammond's scheme:

> . . . Mr. Hammond conceived the idea of reflectors which should cover the entire top of a sound-proof case. The reflectors are parallel revolving slats which can be opened or closed at the will of the player by the extra pedal in very much the way the old fashioned slatted window shutter was manipulated

> Since the case is soundproof, as are the metal-faced reflectors, the tone can be built up within the pianoforte and then permitted to escape at will. Furthermore, the reflectors can return to the sounding board a large degree of the energy imparted to the strings by the musician, the amount depending on the angle at which the reflectors are set by the pedal operator with respect to the sounding board. The return of energy to the sound board was suggested to Mr. Hammond by the so-called regenerative action familiar to radio fans. The action achieved in the Hammond device is a sort of acoustic regeneration, maintaining vibrations of the sound board for unusual durations of time.[28]

The Hammond piano was presented in several demonstrations with Lester Donahue as soloist.[29] Later, in 1929, Donahue made an extended concert tour outside the United States, during which both concert pianist and the inventor won praise.

There is some doubt that the idea of using shutters over piano strings originated with Hammond. Charles Mehlin wrote, in 1925:

> I have been intensely interested in the article describing a new swell-effect for the piano, and am much pleased that the piano industry has been afforded a little limelight in connection with it. A series of shutters over the strings, as he Hammond describes the invention (?), is no invention at all. We have one here in our factory, fitted to one of our type 24 grands, the invention of Dr. Kurt Hetzel, the Bavarian orchestra leader, which was demonstrated by him at our Fifth Avenue warerooms a few years ago.
> . . . .
> My father, Paul G. Mehlin, made just such a shutter arrangement as Mr. Hammond about fifty years ago, ...[30]

Although the Hammond piano attracted a good deal of attention, it disappeared after a few years.

The stage was now set for the application of electricity to the piano--an attempt to create an instrument with truly new tonal and expressive capabilities.

In 1930, Simon Cooper, Brooklyn scientist and engineer, introduced his Crea-Tone, an invention to prolong the piano's tones. This instrument represents a half-way point in the evolution of the piano from the acoustical to the electronic design. The Crea-Tone used electrical circuits to maintain acoustical vibrations in piano strings. Conversely, the true electronic piano uses vibrating strings (or reeds) to generate electrical oscillations--the acoustical vibration of the strings is not heard. The Crea-Tone was a piano fitted with electrical feedback circuits designed to maintain any string in vibration so long as its key was depressed. Joseph Schillinger reported that the ". . . musical characteristic of the tone, which is produced by the help of electro-magnetic induction of the strings, is the absence of vibrato."[31] The Crea-Tone made it possible to achieve an indefinitely continuous sound, but at the same time allowed one to play the piano as usual. A lyrical melody with staccato accompaniment could be obtained. A reviewer described a concert given at the Wanamaker Auditorium in New York City:

> The effect of the sustained tones, with varied dynamic gradations and nuances being obtained by use of a pedal was striking, especially in Chopin's "Etude in E Major." The increased prominence of overtones which the device apparently brought out, as well as the extra sympathetic vibration, resulted in many unusual effects. To the auditor the notes lost their characteristic pianistic quality and took on poetic and mixed timbre, suggestive of the same note being held simultaneously by an English horn, and also saxophone and an old-fashioned small reed-organ.[32]

Little is know about the Crea-Tone's subsequent history.

The acknowledged pioneers in the development of the electronic piano are Benjamin F. Miessner, and the German Oskar Vierling. It is certain that they were aware of each other's work. In Vierling's doctoral dissertation Das Elektroakustische Klavier we find:

> During the development of this subject the American B. F. Miessner, who had simultaneously worked on the same problem and who had reached identical solutions, visited me. This permitted us to cooperate closely in our endeavors and I want to express my appreciation to him as my collaborator.[33]

Benjamin F. Miessner (1890 -) has had a distinguished career as an American inventor. When Miessner opened his electronic music laboratory in 1930, he already had twenty-five years of training and experience in radio and electro-acoustics. In 1909, while serving as a wireless operator at the Naval Radio Station in Washington, Miessner invented the improved "cat-whisker" detector, which came into universal use on the crystal radio sets of the time. Several years later, Miessner pioneered the principles that have led to heat-seeking missiles of today. He designed a wheeled box called the Electric Dog which demonstrated the principle of phototropism. When a strong light was pointed at the "dog" it affected photoelectric cells that operated relays which caused the device to move toward the light. Variations of the scheme were used in burglar alarms that were triggered by an intruder's light. In 1920 Miessner established an acoustical research division for the Brunswick Phonograph Company of Chicago. Here he pioneered many of the important principles of electrical phonography. Several years later he produced for Garod Radio Company some of the first radios powered by alternating current. Under patents protecting his solution to the a.c. "hum" problem in vacuum tubes, he licensed most of the radio industry, including Stromberg-Carlson, Federal, Zenith, General Motors, Crosley, and Howard. In 1930 RCA bought Miessner's basic radio patents for the sum of $750,000,000.

In 1930 Miessner set up a laboratory in Milburn, New Jersey, and began to electrify every conceivable instrument, including the saxophone, clarinet, violin, guitar, kettle-drums, organ, piano, and even the harmonica! Miessner's interest in the electronic piano was stimulated by his brother, Otto Miessner, then head of the University of Kansas music department.[34] Otto Miessner dreamed of a portable piano suitable for music teaching that would be aesthetically pleasing, but inexpensive. As Benjamin F. Miessner laughingly said, "He [Otto] wanted me to make an electronic piano that you could sell for ten dollars!"[35] Otto had previously collaborated with Benjamin in the construction of the Optigraph, a device to (visually) display notes played on a keyboard, and the Rhythmicon, a device capable of performing complex rhythmic patterns. So, in 1930, B. F. Miessner set out to build what he now considers to be his greatest achievement, "the stringless electronic piano."[36]

Miessner's work with the electronic piano evolved in several phases. In the first experiments he tried vibrating reeds, tuning forks, rod, and bars. He found, however, that their output lacked the necessary richness of harmonic structure needed to imitate piano tones. Special hammer-struck string arrangements were tried, but were found to require too-frequent tuning.[37] Miessner then began using conventional pianos with the soundboard cut away to minimize direct acoustical tone, with magnetic, electrostatic, and other types of string vibration pickups.[38] With this last type, Miessner moved from the experimental stage toward the production of his first commercial model.

Miessner's <u>Electronic Piano</u> was essentially an acoustical piano, lacking a soundboard, and having a separate electrostatic pickup for each string group. Miessner gives a synopsis:

> My electronic pianos use no soundboard, but the strings do bear on a bridge supported by a skeleton structure of ribs. This construction permits a struck string to vibrate other unstruck strings through sympathetic vibrations conveyed to them from the struck structure. Also this vibrating structure reacts back on the vibrating string itself to alter its vibration. Since subtleties of pianistic tones depend considerably on these actions and reactions, my piano strings are supported on such a vibratile structure, which has the same action in these respects as in a conventional piano, with the exception, however, that its sound radiating efficiency is vastly reduced. My purpose is to subdue, as much as possible, this direct mechanically produced acoustic tone, and to provide instead of it electronic apparatus in the form of pickup, and amplifying control, and reproducing devices--for tonal development out of the string vibration. These electrostatic pickup devices do not respond in the least to air-borne waves. They do, by their proximity to the strings, translate the string vibrations into corresponding electrical vibrations which are amplified and reproduced electrically.
>
> . . . .
>
> My pickup apparatus utilizes a separate device for each of the eighty-eight separate string groups of the piano scale, and each of these is separately

> adjusted when the piano is made, both for tone quality, by placement along the strings, and for tone amplitude, by regulation of its distance from the string. In this way the whole scale is tone-regulated. Additionally of course, the hammers may be regulated for changing the tone qualities they elicit from the strings themselves, as by softening with needles, hardening with lacquer, and sharpening or blunting them by filing.[39]

Miessner used the characteristics of a vibrating string to his advantage in order to control the timbre, voicing, and envelope control capabilities of his electronic piano. By placing pickups at various points along the vibrating string one can pick up various harmonics that may be mixed in any proportions to obtain various tone colors. Miessner pointed out that a pianist could stipulate the tone quality he desired, and the pickups could be placed accordingly. He also supplied treble and bass controls to further alter the timbre after a basic pickup configuration was selected. Miessner points out another, more subtle way of varying the timbre:

> Further variation in amount of tone is provided in the volume control, with which the performer can set the maximum sound power obtainable, but leaving to him still complete dynamic control over individual tones through keyboard touch. Some interesting effects result from its use. For example, he may set his amplification weak and play with fortissimo touch on the keyboard. This produces brilliant tones but at low power. Conversely he can set his amplification strong and play with pianissimo touch, which produces dull tones at high power. This latter effect is similar to the broadcasting technique of some singers who sing softly

> with high amplification and produce the smooth quality of a soft voice at the volume of a loud and more strident one. In the conventional piano this is wholly impossible, as are those effects previously mentioned. The pianist with a soundboard piano can produce only soft tones at low volumes and brilliant tones at high volumes. These two characteristics of quality and power simply cannot be dissociated from one another and separately controlled. But with electronic tone production principles there is not the slightest difficulty in doing this.[40]

Voicing the electronic piano was simply a matter of placing the pickups at various distances from their respective string groups, thereby altering the strength of the vibrations received.

Envelope control called for placing pickups at various angles to the vibrating string. When a string is struck, it first vibrates in the direction of the striking force; a short time later the string will also begin to vibrate on a plane perpendicular to the original vibration. By picking up and mixing vibrations on several planes, one could control the attack characteristic. This made it possible to imitate non-percussive instruments with a keyboard instrument. These imitations were facilitated by the fact that the Miessner piano had no soundboard. Without a soundboard to dissipate the acoustical energy generated when the string was struck, the strings were able to resonate much longer than on a normal piano. Organ-like tones could be produced using a special swell pedal. Miessner explained the technique:

> This is done by striking the keys with pedal back and immediately swelling the struck tones in. The percussive is thus completely eliminated and the tones are accordingly very organ-like, although of course they sustain only so long as the strings keep vibrating.[41]

Miessner introduced his piano during the early nineteen thirties, with the assistance of Anton Rovinsky, pianist. In February, 1932 Miessner participated in a lecture demonstration given before the New York Section of the American Institute of Electrical Engineers. The session, entitled "The New Music of Electrical Oscillations," featured Miessner's electronic piano, R. H. Ranger's Ranger-Tone Electric Organ, and Professor Theremin's ether-wave instruments. In February of the following year, Anton Rovinsky presented a complete recital demonstration of the new instrument at the Aeolian Hall, New York City. The program included selections by Bach, Scarlatti, Chopin, De Falla, Debussy, Ravel, Tedesco, and Rovinsky. Each selection was followed by a comment on the timbre such as: "suggesting a mixture of clavichord and oboe tone."[42] Later appearances included a Carnegie Hall program with Ferde Grofe and his orchestra in 1937, and a program of "Music and Electricity" presented before the League of Composers in 1938.

As he had done earlier in the field of radio, Miessner began licensing almost all of the electronic piano industry. His patents were the basis of the Electronic _Minipiano_,[43] by Hardman, Peck and Co.; the _Electrone_,[44] manufactured by Krarauer Brothers under the supervision of Maurice K. Bretsfelder; the _Dynatone_,[45] by the Ansley Radio Corp.; the _Storytone_,[46] by Story and Clark; and the _Bernhardt Electronic Piano_,[47] a Canadian Licensee. Several of these pianos offered radio and phonograph combinations as an integral part of the piano.

These pianos were especially useful in the dance band. The Krakauer Electrone, for instance, was used in Cracraft's "All Electronic Orchestra" around 1939-1940. The orchestra used electronic violins, guitars, cello, and piano designed by Miessner.[48]

Contemporary with the development of Miessner's early electronic piano, Oskar Vierling and others developed similar pianos, especially in Germany.[49]

In 1931, the German engineer, Hiller, constructed the _Radiopiano_, using a series of electromagnets placed over the strings of a piano.[50]

About the same time, the Bechstein piano company introduced the Neo-Bechstein, an electromagnetic piano constructed from the designs of Oskar Vierling, and Walter Nernst, a Nobel Prize winner in Physics. Nernst worked out an ingenious method of reducing the explosive attack that characterized many of the first electronic pianos. He designed "micro hammers" that would delicately strike extremely thin strings to generate the vibrations necessary to create electrical oscillations. The micro hammers were attached to standard keyboard mechanisms designed in such a way that only the micro hammer was thrown forward the last small distance before striking the string. In this way, normal keyboard action was retained, while the string was struck with only a small portion of the total keyboard mechanism.

The use of these thin strings actuated by the delicate micro hammers produced conditions that were prevalent with the clavichord of Bach's time. Vierling explains the parallel:

> In instruments with little vibration the damping is relatively small since the reflection plays an insignificant part. The tangent piano [clavichord] was therefore already equipped with special dampers which could be applied to the strings by means of a stop pull, the so-called "Lute stop." These dampers had the effect, in addition to reducing the duration of the echo sounds, of pleasantly influencing the timbre. Nernst also had built this contrivance into his grand piano [Neo-Bechstein]. This becomes even more effective through the electric amplification.[51]

Vierling offered another possibility for handling the problem of explosive transients. He designed a two string group for each key, allowing only one string to be struck by the hammer, while the adjacent string vibrated due to resonance and because it received some energy through the common mounting. The resonanting string began oscillating more slowly than the struck string. By placing pickups on the resonating strings the percussive attack could be completely eliminated.[52] It is uncertain if the design was actually used.

Another foreign piano was the Electrochord, manufactured in Germany by the Forster Piano Company. The electrochord was built using designs of Vierling, Miessner, and E. T. Jacobs.[53] Timbre and envelope controls were provided by electrostatic methods developed by Miessner.

Not all of the early commercial electronic pianos used strings as vibrators. Lloyd Loar designed an instrument called the Clavier or the Vivitone that employed plucked reeds with electromagnetic pickup.[54] The tuned steel reeds were clamped at one end and were plucked by keyboard action. Magnetic pickups, with amplifier and speaker, translated the reed vibrations into sound. Little was heard of the instrument.

The early designs due to Miessner and Vierling established archetypes that served as models for many electronic pianos during the late 'thirties and early 'forties. Pianos lacking soundboards, with electrostatic or electromagnetic pickups became the standard in the new electronic piano industry. But these instruments had problems, and obviously did not satisfy requirements for a truly versatile instrument. One of the most important drawbacks with electronic pianos of this kind was explained by Miessner:

> Their performance, though interesting, was not suitable because the tones did not subside fast enough for clearness in rapid passages. The effect was such as is heard on conventional pianos when too much sustaining pedal is used.[55]

This effect was due to the low damping rate of the strings--no soundboard was present to dissipate acoustical energy. Also pianos of this type would not be highly portable, nor could they be cheaper than ordinary pianos, since they necessitated the use of an acoustical piano in the first place. Furthermore, the electronic version offered no advantages in stability of tuning over the standard piano.

To correct these problems Miessner developed an electronic piano which used vibrating needs with electrostatic pickups. In 1955 he wrote: "I went back to reeds again in my recently developed electronic piano. They are simple, rugged and can hold their tuning for decades."[56] The new type of piano had thin steel reeds a quarter of an inch wide. The reeds were struck by key-actuated hammers with a very simple action. This action used the principle of the "dash-pot," or centrifugal force, instead of the friction-damping mechanism invented by Christofori in 1709.[57]

The use of reeds for the electronic piano offered several inpediments, as Miessner explained:

> Reeds have been successful only when maintained in continuous vibration, as in reed organs, accordions or orchestral reed instruments. They have never been found useful in true musical instruments of the percussion family. Their overtones are few and completely inharmonious with one another.[58]

Miessner solved the problem by striking each reed at its third partial's nodal point, and placing the pickup at the second partial's nodal point. This left only the fundamental vibration to be translated by the pickup. He then designed the pickups so they themselves--in conjunction with electrical circuitry--would generate a fundamental with a series of odd and even harmonics. The pickups were of machined brass and were placed near the free ends of the reeds, which were clamped at one end. The pickups acted as stators of variable capacitors, while the vibrating reed acted as the moving plate. The changes in capacity caused by reed vibration caused a five megacycle oscillator to produce a frequency-modulated signal. This signal was then demodulated into audio frequencies by an FM detector.

The way Miessner designed the pickup to produce a series of harmonics, while the reed was vibrating sinusoidally, was ingenious. Each pickup was the same thickness as a reed (.032 inches). The pickups were adjusted to overlap the edge of the reed by one-half the reed's thickness. The output tone quality could be varied by adjusting the amount of overlap. If the pickup was moved farther away from the normal half-lap position, the fundamental would be emphasized. If the pickup and reed were set flush, the output would be twice the reed frequency. Since the pickup was normally set at the half-lap position, the output when the reed moved symmetrically would be an asymmetrical wave having odd and even harmonics. This wave was modified by audio frequency tone-forming circuits, and a synthetic piano tone was produced. The realism of the instrument was further enhanced by circuits which approximated some of the characteristics of the standard piano soundboard; e.g., a rather sharp roll-off below 100 hertz.

Miessner's piano, which served as the basis for the modern *Wurlitzer Electronic Piano*,[59] satisfied many of the features that Otto Miessner dreamed of. Benjamin Miessner wrote:

> The electronic piano can be much smaller, lighter and cheaper than its predecessors. The basic model, cabinet containing keys, action, reed pickup assembly and FM preamplifier, weighs 75 pounds and can be handled easily by one man. This reduction in weight, bulk and cost is due to the reed action, which makes it possible to abandon the long strings with their aggregate tension of about 20 tons which necessitates the heavy cast-iron plate and bulky wood buttressing. The large-area soundboard is also abandoned.
>
> . . . .
>
> This new stringless piano may be the forerunner of a whole new class of electronic musical instruments of widely differing tonal performance. The lowly fixed-free reed, virtually the "sow's ear" among musical vibrators had become the "silk purse" of electronic design and technique with the great advantages of low cost, weight and bulk, silence when desired with headsets and the ability to stay in tune for many decades.[60]

The use of vibratory generators in electronic musical instruments was not limited to pianos. Many experiments were made using vibrators which produced continuous organ-like sounds. One problem with such an instrument is maintaining constant motion in the vibrator to make continuous sound available. Several interesting methods have been suggested. S. K. Lewer maintained strings in constant vibration by feeding some of the output current from the amplifier back to the string, using an electromagnetic arrangement to deflect the string and maintain its vibration.[61] Miessner suggested a similar arrangement using reeds as vibrators.[62] Lewer tried to maintain strings in vibration using air jets, but found it difficult to maintain vibration in strings of small diameter or length where tension was high. Since this made it difficult to maintain strings in vibration for tones higher than 800 hertz, Lewer abandoned the experiment.[63]

The most successful organs using vibrators have used electrostatic translation of wind-blown reeds. Miessner developed several instruments of this type in the early 'thirties. This kind of instrument had two or more electrostatic pickups mounted near each vibratory reed. The sound could be initiated mechanically, by a key opening an air valve and causing reed vibrations to begin, or electrically, by keying the voltage at the pickups, using reeds kept in constant vibration. In the latter case, the acoustical sound produced by all the reeds operating at once must be damped, or the noise would be objectionable. Miessner points out the pros and cons of electronic reed organs:

> The reeds are very simple, cheap, and stable vibrators, easily maintained in vibration by an air stream of very low pressure and volume; the electrostatic translation devices need only be screws, adjustable in distance, for voicing; the timbre control devices are merely voltage regulating potentiometers, for preselected, or for stop manipulated timbre controls. No complicated timbre circuit wiring, or complicated key switches are

> required; the keys merely open air valves, one for each group of reeds. There are no problems of exact speed control as in rotational generator devices, to avoid frequency drift, or of highly accurate machine work to avoid other undesired rotor or gear effects; the true tempered scale of frequencies, and partials tuned precisely to true harmonic frequencies, present no difficulties. Furthermore, the musically ideal tone envelope is automatically provided by the inability of the reeds to start and stop their vibration abruptly. Last, but very important, is the ability to provide true choir effect timbre mixtures, characteristic of pipe organs, orchestras, or voice groups.
>
> There are, to be sure, some disadvantages with reeds. There is some difficulty in adjusting them for rapid speaking, especially at low pitches, while frequencies above five or six thousand are not very practical. There is also some difficulty, where several reeds are always blown together for each note, in tuning them to exact harmonic frequencies, although the same problem exists to an even greater degree in pipe organs with mixture stops. Again, where complete control of each harmonic is desired, there is a little difficulty in obtaining sine wave outputs from the reeds; for building up tones of numerous separately controllable components, one reed for each component must be used for each fundamental pitch of the organ, so that the number of reeds grows large. For example, in a single manual instrument of 61 notes, providing separate control of ten components, and none higher than 6000 cycles, several hundred reeds are necessary.[64]

One of the most important features of organs of this type is the method which permits easy production of numerous timbres from one vibrator. Miessner points out several ways to accomplish this:

> Two or more electrostatic pickup electrodes are mounted near each vibratory reed tongue, particularly on its opposite sides in the direction of its vibration. Control of the polarities and magnitudes of the charging voltages on these electrodes produces distortions of the translated wave form of the reed motion, so that various electrical wave forms may be produced from a given, fixed, reed-vibration wave form, and thus a considerable range of output harmonic composition is obtained. . . .
>
> In one of these instruments several reeds tuned in harmonic ratios such as first, third, fourth, fifth are provided for each key of a manual, and these are blown together by the air stream permitted to flow through them when the key is depressed. . . .
>
> All of these reeds are provided with electrostatic translation pickup electrodes, at least two per reed, front and back. The front electrodes of all fundamental, or first partial, reeds are connected together, and the charging voltage impressed on them is controlled as to sign and magnitude by a potentiometer. The back electrodes are similarly connected, and their voltage simultaneously controlled. Each of the other sets of reeds tuned to harmonic frequencies is similarly arranged.[65]

The arrangement with four reeds per note and two pickups per reed provided eight timbre controls for a single manual. The timbre could be further changed by making the translation from each reed linear or nonlinear in many variations. The nonlinear form was necessary for the production of very high harmonics, since the linear output voltage from any reed is concentrated mostly on several low partials.[66]

The first commercially produced organ of this type was the <u>Everett Orgatron</u>, manufactured by the Everett Piano

Company from 1934 to 1940. This instrument was designed by F. A. Hoschke,[67] based on patents of B. F. Miessner.[68] The Orgatron had a bank of reeds for each timbre, with pneumatic coupling devices for blowing more than one reed with a single key. This arrangement allowed the introduction of octaves and various timbre mixtures. A brochure published by the Everett Piano Company outlines some of the claims made for the instrument:

> . . . this new Orgatron conforms to the standards and recommendations of the American Guild of Organists as adopted in May, 1933. Its tones are natural and normally produced. Organ literature can be played as written. Model STM-1 is a five-stop, single-expression, duplexed, two-manual and full 32 note pedal clavier instrument. The new Orgatron looks, sounds, and plays like a pipe organ![69]

The Everett Piano Company was acquired by Wurlitzer Organ Company after World War II. The Wurlitzer Company continued to make instruments using the wind-blown reed design until recently.[70] The later Wurlitzer models used reeds that vibrated continuously, with electrical enveloping.[71]

Several articles have been written describing simplified designs for an electronic reed organ. Frederic D. Merrill, Jr., formerly one of B. F. Miessner's associates, described a simple electrostatic method suitable for the amateur constructor.[72] W. K. Allan described details of an electronic reed organ using contact microphones mounted on the reed boxes.[73]

George F. Gubbins invented the Radareed Organ in 1950, using reeds fitted with pipe-like resonators. The electronic portions of the organ were used to amplify and reproduce the acoustical sound of the reeds as altered by the resonator pipes. The instrument created little impact.

In general, most of the instruments using vibratory tone generators have been instruments incapable of producing an indefinitely sustained tone, e.g., the electronic piano. With the exception of the Orgatron, and the early Wurlitzer electronic organs, most electromechanical organs have used rotating tone generators. Instruments of this type use tone generators comprising wheels or disks; each one rotating at a constant speed to produce a periodic pattern of electrical oscillations. Translation of the kinetic energy of the wheel to electrical energy can be accomplished with photoelectric, electromagnetic, or electrostatic arrangements. Ideally, any rotating tone generator should conform to certain basic requirements. These requirements dictate that for each wheel, the number of indentations, teeth, holes, photographed wave shapes, or whatever is responsible for creating periodic electrical currents, must be integral and the spacing between them must be exactly equal. If this requirement is not met, noise or faulty intonation will be introduced as a component of the output. Unfortunately, since no two musical frequencies (except octaves of a note) have an integer common denominator, it is very difficult to meet the requirement of integer relationship, and build a single disk that will produce all the notes of the equi-tempered scale. Richard Dorf explains the problem:

> . . . if the disc is rotated a 6.125 rps (367.5 rpm), the 16 hole outer band produces G-98 cps and the 8-hole inner band yields the G an octave lower at 49 cps. You will find that there is no other integral [integer] number of holes which could be used at this speed to produce any other musical note [of the equitempered scale]. In fact, you will have to have discs going at 12 different speeds to produce the 12 different tones.[74]

However, since successive octaves remain in the 2:1 ratio, it is easy to produce all octaves of a note with only one tone wheel. A wheel with seven bands of holes, the outer band having 512, the next octave having 256, and so forth, can be rotated at 6.125 rps to produce a high G (3134.95 hertz), a low G (49 hertz), and all intervening octaves. Thus an instrument of several octaves can be made using only twelve tone wheels. Many instruments have made use of this principle.

One of the oldest, and most popular designs for rotating tone generators has been the photoelectric method. The roots of this method can be traced to 1888, when Ernest J. P. Mercadier used a rotating light interrupter and light sensitive cell to provide alternating currents for multiplex telegraphy.[75] Photoelectric methods of scanning may be divided into two main groups: those which employ an illuminated stationary slit that is modulated by a passing variable-area mask; and those in which the mask is stationary and illuminated, and is modulated by the movement of a series of light-interrupting slits one fundamental wavelength apart. In either case, the interrupted or modulated beam of light is focused on one or more photoelectric cells, the output of which is amplified and translated into sound.

Many inventors have experimented with photoelectric tone generators, although not all of these experimentations have resulted in complete or commercially feasible instruments. In 1916, H. J. Van der Bijl described a photoelectric instrument that was played by paper tape.[76] A long rotating cylinder capable of being rotated at a constant speed housed a source of light. Rays of light passed through perforations in the cylinder creating periodic flashes of light. These flashes were reflected by white marks or absorbed by the black background of the paper tape. Those reflected acted upon a selenium cell to create periodic electrical pulsations necessary for sound production. Others using a hollow rotating cylinder design include: C. R. MacCullum and A. MacCullum;[77] Ralph K. Potter;[78] and P. Toulon.[79] B. F. Miessner designed photoelectric scanning systems as early as 1922, and disclosed, in 1926, a patent application describing a musical instrument using these principles.[80] The Frenchman E. Hugoniot patented an instrument of the stationary mask type in 1921.[81] He used disks with intermittent slits which passed over photo electric cells fitted with shutters. The shutters were cut according to a definite wave shape, regulating the illumination of the photoelectric cell and therefore, the timbre of the tone produced. The device resembled an experimental layout more than a complete musical instrument. In 1929 in Germany, A. Schmalz improved this arrangement with the addition of "phonograms," or accurately etched waveshapes, using different phonograms placed over a series of shutters. This allowed a greater variety of timbres from a given generator.[82] At the same time in this country, Earle Kent suggested a photoelectric instrument with rotating disks of phonograms arranged in circles.[83] In 1925, R. Michel patented a procedure for making photographic notation of tones--similar to the technique used in sound motion picture films.[84] P. Toulon arranged film strips of this type in drum form to create a photoelectric instrument.[85] Others who have described rotating generator designs for photoelectric instruments include: S. Prisner; A. H. Brackensey; G. T. Winch; P. T. Hobson: and H. G. Matthews.[86]

Several photoelectric instruments using neither rotary nor vibratory generators have been proposed. Nicholas Langer and J. Halmagyi designed a system in which the periodic flashes of a gas-discharge tube were used to modulate a photoelectric cell connected to the input of the main tone amplifier.[87] R. W. Bumstead suggested an unusual system that used an iconoscope which scanned a silhouetted wave-pattern projected on its screen.[88]

Several experimenters built photoelectric systems for the purpose of exploring psychoacoustic phenomena. E. G. Richardson[89] and J. F. Schouten[90] built devices of this sort. These instruments resembled laboratory apparatus more than musical instruments. However, in 1957 Henk Badings and J. S. de Bruyn used Schouten's device to help create electronic music montages for the ballet music "Cain and Abel."[91]

Several photoelectric musical instruments have been suggested for the amateur constructor. These include designs by: Rollin E. Cambell and Lyman E. Greenlee;[92] Lyman E.

Greenlee;[93] and Leslie Gould.[94]

Only a small percentage of the designs for photoelectric instruments has resulted in complete instruments that have attracted public attention. Commercial production of photoelectric instruments represents a still smaller number. Although there are no photoelectric organs on the market today,[95] a number of inventors and musicians have built and used photoelectric instruments. One of the most complete early instruments was the Cellulophone, constructed during the early 'thirties in France by P. Toulon. This instrument used stationary wave-form masks arranged radially, with different wave shapes for each timbre. A disk with slits arranged in concentric rows over the wave forms rotated in front of the wave forms. The rows of slits were arranged at different diameters from the center of the disk, creating successive concentric rings that were proportional to frequencies of the equitempered scale. In this arrangement, one rotating disk with associated wave forms was required for each successive twelve semitones. This design did not meet the requirement of integer relationship among the rows of slits. For this reason, tuning inaccuracies in the instrument were greater than the normally acceptable 0.1 per cent limit.[96] However, the design did offer some interesting musical possibilities. Since each complete octave of keys on the manual keyed a single disk capable of producing several timbres, it was possible to perform with a different timbre in each octave of the instrument. Other designs which used a single disk to produce several successive octaves of a given note would not have this capability. Toulon used an optical arrangement that concentrated the interrupted light beams from all the notes (including different timbres) of a given octave into a photocell. The shuttering of the beams of light associated with individual notes was achieved by small electromagnetically actuated shutters operating at the focal point of the individual beams. Four tungsten-filament lights were placed in a row, with two disks arranged symmetrically on either side of each light. The instrument thus had an eight octave range. Photos of the Cellulophone in an article by Toulon show a finished instrument with two manuals and several octaves of pedals.[97] Although Toulon had the backing of several business firms,[98] the Cellulophone never became popular.

About the same time Emerick Spielman, an Austrian, introduced the Superpiano, a photoelectric instrument based on the work of Thiring, an early experimenter. Little is known of Thiring's instrument, except that it used twelve disks with holes that stood in octave relationships--a typical design. Spielman's contributions included the perfection of the keyboard switching arrangement. When a key was depressed, a flexible band of metal came into contact with a variable resistance, gradually covering it. As the resistance was more fully covered, the strength of current and hence the volume of sound produced was increased. The Superpiano was therefore touch sensitive--to the extent that the performer could master the difficulties of depressing the keys to various depths. Spielman's instrument used twelve disks of blackened film with light holes standing in octave relationships. Each disk rotated at the appropriate speed to produce the equitempered scale. Spielman foresaw expanded possibilities for the design of the Superpiano:

> If, instead of mathematically calculated rows of holes on the tone plates of the Superpiano, photographic reproductions of single instrumental tones were fixed--a method known and accomplished since the sound film--the Superpiano would reproduce tones of this color in the loudspeaker. . . . For example it is possible to make a photographic record of the most perfect tones of Kreisler or Caruso, and adapt them to the tone records of the Superpiano. The Superpiano will then not only sound with tone colorings of Kreisler's violin or Caruso's voice, but will compel the former to play contrabass and the latter to sing bass.[99]

Spielman also foresaw new theoretical possibilities with implications for composition:

> There are future possibilities for music which the Superpiano can and will realize owning to its inherent powers. One can produce unlimited or theoretically determined tone scales on it. . . . aside from the realization of the whole tone scale, a mathematically exact quarter or eight tone scale can easily be built. With reference to tone coloring the Superpiano offers possibilities to enter upon untrodden ground. . . .
>
> . . . the Superpiano will need but a small time for the full realization of the vast possibilities dormant therein.[100]

The instrument did not attain this predicted success.

In this country Arthur C. Hardy and Sherwood F. Brown constructed an unusual photoelectric organ. The Hardy-Goldthwaite Organ was built around 1930, using ideas of Du Val R. Goldthwaite, a patron of the arts in New York City.[101] In this instrument, all the frequencies of the equitempered scale for a pitch range of seventy-one notes were recorded photographically on a single disk. Separate disks were used for each tone quality. Because of this design, which did not use concentric rings in integer relationship (such as the octave), the inventors had to overcome the abrupt click that many of the wave tracks created due to sudden phase shift. Hardy devised an ingenious method to minimize these sudden phase shifts which occurred at the mutual beginning and end of each circular wave track. Instead of allowing all of the phase shift to occur at one point, it was divided among several points spaced equally around the wave track. In this way only a fraction of the total phase shift occurred at any one point. The keyboard keys operated shutters to key the modulated beams of light. According to Miessner, the Hardy-Goldthwaite Organ used wave tracks ". . . translated from recorded waves of original [acoustical] instrumental sound."[102]

In 1936, The Welte Organ was introduced in Germany, using the same principle of photographic reproduction of acoustical instrumental sounds. Other design features were radically different from the Hardy-Goldthwaite Organ. The Welte Organ, which was produced commercially before World War II, had glass disks carrying photographic tone patterns. The tone patterns produced not only successive octaves of the same note, but provided a selection of timbres in each octave as well. Unlike many previous instruments, the scanning slits of the Welte remained stationary, and the glass disks were rotated. Also, the instrument was unusual because the glass disks could be removed and changed at will, making various tonal specifications possible.[103] In fact, Edwin Welte had hoped to bring the tones of world famous organs to music lovers everywhere by recording sound tracks from actual stops of famous European organs.[104] Unfortunately, the instrument was destroyed during the war, and the project was abandoned.

Arnold Lesti and Frederick M. Sammis built several photoelectric instruments in this country during the early thirties, including Lesti's Radio Organ of a Trillion Tones,[105] and the Lesti and Sammis Polytone.[106] Both instruments used a design with stationary wave forms and rotating tone wheels. The Trillion Tone Organ was an early model. The later Polytone was a three manual instrument with five octaves and many timbres. Still later, Sammis constructed the Singing Keyboard,[107] a photoelectric sound effects machine. Little is known about the subsequent history of any of these instruments.

One of the most prolific inventors of photoelectric musical instruments was Ivan Eremeeff, who worked in conjunction with Leopold Stokowski in the electronic music laboratories of the WCAU broadcasting station in Philadelphia.[108] Eremeeff, a Russian physicist, conceived of a number of photoelectric musical instruments,[109] and built several. The Syntronic Organ was an unusual instrument that had a "pitch track" capable of running like a motion picture for about an hour. The pitch tracks were recorded on film using a device having cams to chop light into eight separate tracks standing in octave relationships. The process was repeated to create frequencies for the equitempered scale. As this pitch track passed the photoelectric cells with associated masks, the light beams were modulated. The timbre depended on the shape of the mask. Eremeeff provided a roll of masks on film that could be cranked over the photocells--numerous timbres were possible. Erefeeff and Stokowski had ambitious plans for this instrument. E. E. Kassel reported:

> At the present writing [1934], plans are being discussed with a view to a symphony orchestra which is composed exclusively of electronic organs [see U.S. Patent 1,924,713], of which there will be about 35. These instruments are designed to be portable and compact, and will utilize the synthetic wave films as described, for the production of various types of music, such as produced by ordinary well-known musical instruments as the violin, the flute, the clarinet, piccolo, etc., <u>and also music the timbre or tone of which has not been heard before</u>![110]

In 1935, Eremeeff introduced the <u>WCAU Photona</u>, a photoelectric instrument of simpler design. Kassel maintains that the Photona was the first commercially-made electronic musical instrument. He traces its history:

> . . . the first commercially-made instrument was constructed under a contract awarded, by a Philadelphia broadcast station [WCAU], to Ivan Eremeeff, chairman of the Society of Electronic Music, on July 2, 1933, and was delivered in the beginning of February, 1935. This instrument made its official debut on February 10, 1935, according to nation-wide press reports, and was officially presented to the public over coast-to-coast radio broadcasts and abroad, for 6 months, beginning on April 6, 1935.[111]

The claim that the Photona was the "first" commercially produced instrument is not true. Cahill's Telharmonium, a colossal commercial undertaking, predates the Photona by some thirty years. Also, other previous instruments could not be labeled solely experimental, even if the inventor did not receive a commission specifically directing him to build his instrument. The Photona used a very simple system of twelve rotating light choppers, that worked to interrupt light periodically. Evidently no tone masks were used--the output was probably a complex wave. The twelve disks were cut radially with slots at several depths toward the center of the disk, allowing for the production of harmonic or inharmonic overtones. The instrument is reported to have used 900 lamps, switched on by keys, for the production of sound.[112]

Although many designs have been suggested for photoelectric musical instruments, the type has disappeared from the market, having had only token commercial production. The Baldwin Company produced a photoelectric model in the fifties, and Kimball made one for a short time, but both instruments were short-lived.[113]

On the other hand, organs with rotating tone wheels and <u>electromagnetic</u> pickups have survived the general transition of the electronic musical instrument industry to tube-type or solid state instrument design. The highly successful Hammond Organ, a rotating-wheel electromagnetic organ introduced in 1935, is still on the market. Although the Hammond is the most successful of this genre, it was not the first electromagnetic instrument.

A rudimentary form of the rotating electromagnetic design can be traced to the invention of the magneto.[114] The rotating tone wheel, or phonic wheel, was used in telegraphy and telephony, and was first described in Emile Berliner's patent of 1882.[115] The earliest complete musical instrument of this type was Thaddeus Cahill's Telharmonium, built in 1897.

The simplest form of this design consists of a number of iron disks, having convoluted peripheries, mounted on a shaft, and arranged to rotate in front of an electromagnetic pickup; the frequency produced is dependent on the number of convolutions and the speed of rotation. Rotation of the wheel gives a wave shape that approximates the pattern of indentations on the wheel. The tone wheels can be shaped to output near-sinusoidal waves, or complex waves. If the first method, employing additive synthesis, is used, many individual tone wheels must be provided to create the harmonics necessary for timbre control. In the latter case, called subtractive synthesis, timbre can be controlled by shaping the complex waveform through electrical circuitry external to the tone generators themselves.

Many of the early experiments with rotating electromagnetic tone generators did not result in complete instruments that attracted public attention or commercial backers. In 1910, K. Ochs, a German, patented an arrangement for an electromagnetic instrument.[116] Ochs tried to simplify Cahill's design, with its many tone wheels, by providing only three disks which were divided into many segments to create the scale. The face of each disk was divided into twenty-four concentric circles that were fitted with alternating segments of conducting or insulating material. The disk was therefore a rheotome, or circuit interrupter, for twenty-four frequencies within a two octave range. Three such disks were rotated in the ratio of 1:4:16 to produce an instrument of six octaves. Vierling commented that "this simplification against that of Cahill is . . . specious, for it is based essentially on a limitation of the combination possibilities for the production of various timbres."[117]

In France, E. Hugoniot devised several electromagnetic tone generating systems during the late 'teens.[118] In one of these he used many identical tone wheels that ran with different speeds of rotation. The stator, or stationary pickup area, was in a ring shape which circumscribed the periphery of the rotating disk. The stator was divided into six equal segments, each of which accounted for sixty degrees of the ring. A number of magnetic pole pieces were placed in each of the six zones. The number of pole pieces placed in successive zones was proportional to the ratios of the first six partials of the overtone series; this created six currents in harmonic relationship that could be mixed by regulating the strength of the separate magnets. In a later arrangement, Hugoniot used many separate tone wheels with numbers of notches corresponding to partials--a typical arrangement. Still later, he devised irregularly shaped wheels that ran before electromagnetic pickups to produce a complex wave shape.[119] O. Fischer tried a similar arrangement, but also provided a pedal which would bring up different sets of disks in order to change the timbre.[120] Another experimenter who built additive synthesis systems of this sort during the twenties was A. Zouckermann.[121] He used an arrangement of several induction coils around each tone wheel to produce the fundamental and partials.

In 1920 K. Fiala pioneered an unusual method of tone production using rotating tone wheels.[122] This method became known as the "Poulsen" method because of its similarity to the Telegraphone, or Telephonograph, an early audio recording device invented by Valdemar Poulsen.[123] Fiala transcribed electromagnetically the sounds of acoustical instruments onto steel disks, using a microphone and transcription magnet. The disks were combined in an instrument, arranged according to their pitch and timbre, fitted with electromagnetic pickups, and connected to a keyboard. E. Hugoniot,[124] R. Michel,[125] and A. Douilhet[126] also developed instruments of this type.

Most of the early rotating-wheel instruments were of the additive synthesis type; timbre changes were obtained by mixing (adding) various sinusoidal frequencies. However, Oskar Vierling, and J. Bethenod[127] developed rotating complex-wave tone generators with provisions for altering the timbre with electrical circuitry. Vierling pointed out that various waveshapes could be picked up by placing induction coils (electromagnetic pickups) at various distances from the tone wheel. Other techniques suggested were non-linear amplification, and the use of resonant circuits for timbre modification.[128]

During the nineteen-thirties, many inventors moved from the experimental stage and produced instruments that were presented to the public. Some instruments were subsequently produced commercially. Morse Robb developed an unusual instrument, the Robb Wave Organ, that was manufactured in Canada during the thirties.[129] The Wave Organ used complex waveform electromagnetic generators--using one disk per note. The wheels were bound into a cylinder-like arrangement which was rotated in front of magnetic pickup coils. The unorthodox tone wheels had complex waves engraved on the edge of each wheel. Waveforms produced by the generators could be mixed in various proportions to produce unusual timbres. Little is known about the Wave Organ's subsequent history.

Another unusual tone generating design was proposed by A. H. Midgley,[130] but was constructed only experimentally. A number of concentric ridges were cut on the face of a rotatable disk. On the face of each ridge, at a right angle to the plane of the disk, sinusoidal wave forms were cut. Electromagnetic pickups were provided in the form of screws set radially across the disk and opposite the concentric ridges.

Ivan Eremeeff constructed several electromagnetic instruments in this country during the early thirties. The best known instrument was called the Gnome, and used a typical rotating wheel, electromagnetic pickup design.[131] Eremeeff made use of both additive and subtractive synthesis techniques. In an article written in 1932 we find descriptions of both methods:

> The larger instrument, . . . is a synthetic type, operating on principles involving the synthesis of fundamental frequencies with harmonic, sub-harmonic, multiple, and fractional frequencies, for the production of musical tones of predetermined pitch, volume, and tone quality. [additive synthesis of sine waves.]
> . . . .
> The smaller instrument has been called a "Gnome" and works on the same basic principles as employed in the larger type described above. [rotating tone wheels.] However, while the large type obtains tone peculiarities by the accurate synthesis of different frequencies at different intensities, the "Gnome" produces tone quality with the aid of a dial wave-alteration control, in which wave forms are modified by the selective connection of the output circuit to different taps of a transformer, or by a system of condensers which are adjusted by a dail. [subtractive synthesis using filters or formant circuits.][132]

One of Eremeeff's instruments used touch sensitive stationary keys constructed of metal. The performer sat upon a bench fitted with a metal top, the body of the performer thus acting as part of the circuit. This instrument also had a foot operated tremelo device, a volume control pedal, and an envelope controller for the decay of the tone.[133] Evidently, Eremeeff's electromagnetic instruments were not produced commercially.

One of the most interesting of the early electromagnetic instruments was Richard H. Ranger's Rangertone Organ. This instrument, introduced in June, 1931,[134] was certainly the most complex. The Rangertone was said to have over 50,000 separate electrical circuits,[135] and, according to Ranger, a home model would have cost five thousand dollars.[136]

Miessner pointed out Ranger's debt to Thaddeus Cahill and listed some of the features of the Rangertone:

> Ranger's improvements over the basic work of Cahill were made possible by the advent of the vacuum tube. For example he [Ranger] provides means for automatic selection of different amplifiers, for different simultaneously produced tones, to prevent cross modulation in a single amplifier; means for avoiding keying transients, for accentuating high or low frequencies, for restricting tremolo to specific components of a complex tone, and at different tremolo rates, means to provide glissando effects, for regulating the temperament, for providing damped wave trains in simulation of percussive tones, and numberous other details.[137]

Although Ranger used tone wheels similar in function to Cahill's massive alternators, this facet of his design was incidental--Ranger considered alternative methods for tone generation.[138] The particulars of the tone wheel circuit are interesting, however. Ranger used small tuning forks in the circuits to maintain the rotation of the wheels at the proper speed. Obviously, by using different sets of tuning forks, one could have various intonation systems. Only twelve tuning forks were necessary, due to the use of sets of alternators grouped to produce several octaves of a note.

From a musical standpoint, the Rangertone's amplifier-selection timbre control system was the outstanding feature of the instrument. Ranger's amplifier system used separate amplifiers that were made to "track" individual lines as the organ was played. The keyboard was divided into two equal sections, with several amplifiers for each section. In the right hand, the highest three (or more if desired) notes would be routed to separate amplifiers; the lower half of the keyboard had an analogous arrangement.[139] Thus it was possible to play at least six lines with independent tone colors by filtering the output of each amplifier separately. As Miessner indicated, separate tremolos for each line would be possible also.

The Rangertone was demonstrated several times during June, 1931. At one private recital, about twenty editors of music publications heard Charles M. Courboin, organist of the Church of the Resurrection at Rye, New York, play a recital of light classical works.[140] On June 16, Courboin played the Rangertone in its radio debut over stations WEAF and WOR.[141] The program originated from Ranger's home in Newark, New Jersey; probably due to the lack of mobility of the complicated instrument. The Rangertone, with its orchestral-like capability of playing many lines of different timbres, caused speculation concerning its future in the musical world. In one article we read:

> No longer is the composer limited to the tones of traditional instruments. He can now specify timbres. What will become of the orchestra? It is hard to predict. Perhaps a quintet seated at keyboards and controlling electrical devices will take the place of a symphonic organization. Perhaps a new type of virtuoso may arise, a Paderewski and Toscanini fused into one super-performer who deals with a thousand horsepower instead of a company of musicians, and who is able to produce at will a barely audible pianissimo, a crash of brass that eclipses the volume of a dozen military bands or an eerie effect to suggest the fabled music of the spheres. It is a widening of the musical horizon that we may now contemplate, an opportunity for giving fuller expression to creative genious, even though it may be accompanied by another phase of "technological" unemployment.[142]

The Rangertone did not live up to these expectations. Furthermore, the instrument did not become popular for the home, probably due to its complexity and expense. It is doubtful that Ranger had created the instrument for a mass market in the first place.

On the other hand, Laurens Hammond worked for several years to perfect an economical, rotating-wheel organ suitable for mass production. His work resulted in the Hammond Organ, the most widely known example of an instrument using an electromechanical tone generator.[143] The Hammond Organ, introduced in 1935, was based on a modernization of the designs used in Thaddeus Cahill's Telharmonium (1897).[144] The Hammond Organ was made suitable for mass production by the mechanical simplicity of the design, and the miniaturization made possible by vacuum tube amplifiers. Although current Hammond designs have departed somewhat from the original instrument, a description of the early organ gives a good idea of the instrument's salient features. The early models had two manuals and pedals, a tone generating system of ninety-one iron disks driven in pairs from a common shaft, and a drawbar system that facilitated the production of many different timbres.[145]

The tone wheels were mounted in octave relationship in twelve groups--each group being driven by one of twelve brass wheels located on the main driving shaft. Small bakelite wheels were driven by the twelve brass wheels, and the torque necessary to turn the tone wheels was applied through a helical spring. Adjacent to each tone wheel was the magnetic pickup which was placed an average of .005 inch from the tone wheel.[146] The main shaft was driven from a small synchronous motor of Laurens Hammond's design.

The output of these tone wheels was a relatively pure sine wave. Hammond provided harmonic drawbars which allowed the outputs of the ninety-one tone wheels to be mixed as fundamental tones with overtones. Each key on the manual depressed nine switches. These switches were connected, with paladium contact points and some 8.5 miles of wire, to different drawbars situated above the keyboard. By manipulating these drawbars the amplitude of the fundamental and eight overtones would be controlled--ofering "253 million tonal quality combinations," according to several articles written about the instrument.[147]

The Hammond Organ has become a standard of its kind. Sources for a more complete description of contemporary design features are numerous, and will be cited at the close of this chapter.

The ubiquitous Hammond has become so commonplace that most people are not aware of its pioneer origin, and interesting history. The synchronous motor used in the instrument was first used by Laurens Hammond in an electric clock, the first product of the Hammond Company.[148] When the depression caused this market to be flooded with similar clocks, Hammond, an inventor of considerable talents, invented a device that shuffled a pack of playing cards into four piles, and he build the device into a bridge table. Some 14,000 of these devices were sold in 1932, but the line was discontinued, again due to the depression. In 1933, Hammond began to search for ways of using his synchronous motor in a new product. After two years of research, with the help of John Hanert, a research engineer, Hammond constructed and patented his now-famous instrument. The instrument was introduced to the public on April 15, 1935, at the first (and only) Industrial Arts Exposition in Radio City's RCA Building.[149] On the way there, Hanert and Emory Penny, sales manager, stopped in Detroit and gave a demonstration for the company's first customer--Henry Ford.[150] The New York demonstration was greeted with similar enthusiasm. Among those taking their turns at the keyboard of the Hammond Organ that day were Pietro A. Yon, organist of New York City's St. Patrick Cathedral; Fritz Reiner, later conductor of the Chicago Symphony; and George Gershwin, who immediately ordered one for his own use.[151] The list of musicians who expressed a favorable interest in the new instrument included: Leopold Stokowski, Walter Damrosch, Sir Thomas Beecham, Roger Wolfe Kahn, Rudy Valee, Lawrence Welk, and Hal Kemp.

The Hammond Organ created a significant impact on the popular music field. In 1935, Milt Herth auditioned for the organist job at radio station WIND, Gary, Indiana. He got the job and soon established a new style of playing:

> Herth's staccato style of playing the Hammond on WIND and other radio stations caught on quickly

> and became the distinguishing characteristic of his work. His "Stomping at the Savoy" recording in 1936 was the first of many discs that helped build his fame as a leading entertainer of theater, radio and night clubs.[152]

Another well known performer on the Hammond Organ was Ethel Smith, a frequent performer on the radio program "Hit Parade," and "Hit Parade of Old Time Tunes." Her specialty was Latin-American music. She said:

> Latin-American music had long intrigued me, especially the rhythms, and believing the Hammond was particularly adapted to playing this music, I made a trip to South America to study it first-hand, adding Portuguese to my college Spanish. In eight months I had collected a number of examples of the Samba, rhumba, tango, and conga, and found that the Hammond lent itself particularly to these sparkling rhythms. It was while playing at the Copacabana in Rio that I was offered a radio contract in the United States, and returned to accept it.[153]

Others among professional organists who have used the Hammond Organ include: Jimmy Smith, Lenny Dee, Hal Shutz, Rosa Rio, Jackie Davis, Mildred Alexander, Eddie Layton, Axel Alexander, and Shay Torrent.[154]

For many years, "electric organ" and "Hammond" were virtually synonymous. The continuing success of the Hammond Organ Company is testimony to the soudness of the design principles developed by Laurens Hammond and John Hanert.

Another commercially produced organ using rotary electromagnetic tone generators was the <u>Mastersonic</u>, designed by

John D. Goodell and Ellsworth Swedien around 1949. Although only about fifty of these instruments were manufactured and installed,[155] the design concepts are of interest. Basically, the instrument used rotating pitch instead of tone wheels. These pitch wheels resembled conventional gears with teeth distributed about the periphery. Wave shapes were obtained by convoluting the pole pieces of the pickup coils, unlike the Hammond, which used convoluted tone wheels. Obvious advantages include the possibility of using many sets of pickups for each pitch wheel, corresponding to different ranks of a pipe organ. Also tolerances for the pitch wheels were not as critical as with tone wheels. Despite these apparent advantages, the instrument has not survived. Perhaps its drive system for the pitch wheels was unstable. The system employed cone-shaped wooden wheels which came into contact (at the correct angle) with rubber-tired drive wheels. The designers remarked, concerning this arrangement: "Stability of drive requires careful attention to the mechanical reactances and resistances involved, and dynamic balance of the entire system is essential."[156]

The Mellotron is an unusual electromagnetic instrument which does not use rotary or vibratory tone generators. It is essentially a tape playing machine under control of two thirty-five note keyboards. The right-hand keyboard can play slightly less than three octaves of eithteen instruments, prerecorded on multi-track tapes. The left hand keyboard controls a large number of pre-recorded rhythms and seventeen different chords for accompaniment. Alan Douglas describes the unusual method of operation:

> Many different tracks are recorded on these tapes, the heads being moved to select some of these, whilst the actual tapes are divided into sections to further increase the number of sounds available. One of the most satisfactory design aspects of the device is that the playing heads only contact a tape when a playing key is depressed; thus the problem of wear is greatly reduced, if not entirely abolished.
>
> This desirable feature is combined with a pinch roller actuated by a key, so that as well as contacting the replay head, any key pressed starts the tape moving. Because of the three tracks recorded side by side on any one tape, the head can also be moved across the tape to scan the correct track. The movements to initiate this are controlled by the appropriate tone button, operated by the player. If we imagine the instrument in a starting position, the tape is pulled down over a roller by a spring, so that there is none in the take-up box. On pressing a key, the tape is then taken into the box whilst keying. If a key is held to the maximum extent, then we have eight seconds of playing time on each tape section before it is drawn back to the starting position. The tape is therefore ferried back and forth by means of the spring and bottom roller, for when the sound is required, the capstan roller propels the tape in the right direction; when the sound ceases, the spring pulls the tape back to the starting position. Naturally the starts of the tape must be set when the machine is prepared for use in the first place.

> Tone qualities and rhythms are selected by buttons above the playing keys, and an ingenious electrical system inches the tape along until the correct sound--and at the correct time--is in a pssition for playing. For example, if a piano is required, it is essential that the key should pick up the start of the note and not half-way along it. Electronic registration is used to perform this function. An interesting point is that the capstan motor is driven from an oscillator with a controlled frequency, but the register control motor is caused to rotate from the registering pulses through another amplifier. The capstan frequency can be varied somewhat to tune the instrument to the pitch of other instruments playing with it; this would not of course be possible if the drive was at 50 c/s from the mains.[157]

The last class of instruments with rotary tone generators to be discussed is the electrostatic design. The principle involved is the same used in Miessner's *vibratory* electrostatic designs. That is, the production of voltage variations as a function of the capacitive change induced by relative movement of the parts of the tone generator. Any such *rotating* system uses a stator, or stationary disk, and a rotor, or moveable disk to create a series of varying capacitances. In such a system, all homologous elements can be identical, different pitches being obtained by spinning the rotors at the speeds of desired ratios. The typical method of generating tones by a rotary electrostatic system is the scanning by a radial arm (rotor) of a conductive wave pattern repeated continuously around the circumference of a circle (stator). Appropriate wave patterns are etched on a stator covered with a thin layer of conductive metal, leaving islands of conductive material arranged in concentric rings. When the radial arm passes over these wave patterns, a change of capacitance is caused which corresponds to the pattern.

Rotary electrostatic systems offer certain problems which probably account for the small number of instruments that use this method. Due to the way an electrostatic field spreads around a conductive element, complex wave-forms become blurred by a "fringing" effect. The method is therefore unsuitable for the generation of wave-forms having higher overtones. Also, great care must be taken in engraving the wave forms and controlling the gap between the rotor and stator. Any such gap discrepancy or vibration in the rotating elements will show up as unpleasant undulations in amplitude or frequency.

Despite these exacting requirements, several successful rotary electrostatic instruments have been built. One of the earliest was the <u>Electrone</u>, marketed by the John Compton Organ Company, a British firm. This instrument is based on designs of L. E. A. Bourn;[158] early models were demonstrated in 1935. Each of the twelve generators are geared to generate a single tone of the lowest octave and its associated harmonics. The rotary elements, which carry the scanning forms, are geared in the ratio of $\sqrt[12]{2:1}$, creating an equitempered scale. The sinusoidal waveforms are located in the stators, and provide for the synthesis of complex tones by the superposition of the required harmonics using a switching system. Further harmonics are available from separate disks to avoid the more severe intonation discrepancies caused by the use of non-Phythagorean harmonics.[159]

Another design for a sinusoidal electrostatic instrument was suggested by A. H. Midgley and A. M. Midgley.[160] The design used a rotating <u>dielectric</u> between the conducting stators (the "rotor" portion of this generator did not move). The rotating dielectric performed as an interrupter between the inscribed waveform and the other stator. It is uncertain if an instrument was constructed using the idea.

Several designs have been suggested for rotary electrostatic instruments capable of producing complex waveforms. The <u>Dureux Organ</u> makes use of fully preformed pipe organ waveforms produced from cathode ray tube photographs of the actual sounds of acoustical instruments. This French instrument uses silver plated plastic stators and rotors, and is equipped with two manuals and a thirty-two note pedal.[161]

In 1939 Earle L. Kent proposed an electrostatic instrument using a tone generator of super-audiofrequency, the output of which would be frequency modulated to produce audible sound.[162] The waveforms were to be oscillographic photographs of particularly fine pipe organ tones. Similar designs have been proposed by Estell Scott,[163] W. F. Curtis,[164] and Biggs.[165] Evidently no instrument has been constructed using this concept.

Electronic instruments with electromechanical tone generators have virtually disappeared from today's market. They have been replaced by instruments using totally electrical generators. Even the Hammond Organ Company, with its conspicuously successful line of electromechanical instruments, has abridged their early electromechanical tone-wheel design. In the Hammond model X-66, only the highest octave is derived from rotating tone wheels, the remaining notes being obtained by solid state frequency dividers.[166]

Although most of the early polyphonic electronic instruments were of the electromechanical type (photoelectric, electromagnetic, or electrostatic), there were several significant early instruments that were totally electrical. The first were extrapolations from the early monophonic instruments using the simple LC "tank circuit" oscillator patented by Lee de Forest. The earliest purely electrical polyphonic instruments were therefore of the type having vacuum tube sine wave oscillators.

Hugo Gernsback, former editor of "Radio-Craft" and other magazines, was a pioneer in the development of such instruments. He built the Staccatone in 1923, so named due to its abrupt attack. It is uncertain if this instrument was completely polyphonic, but it is known that it was a simple inductance-controlled keyboard instrument.[167] Gernsback played the Staccatone publicly for the first time in November, 1923, over radio station WJZ of New York. The same instrument was used in the Rialto Theater in New York during the following year.[168] The Staccatone was probably the prototype of Gernsback's more important polyphonic instrument, the Pianorad. The following description from an article by Gernsback clearly indicates that the Pianorad was a polyphonic instrument with near-sinusoidal waveform output:

> The musical notes produced by vacuum tubes in this manner have practically no overtones. For this reason the music produced by the Pianorad is of an exquisite pureness of tone not realized in any other musical instrument. The quality is better than that of the flute and much purer. The sound, however, does not resemble that of any known musical instrument, the notes are quite sharp and distinct, and the Pianorad can be readily distinguished by its music from any other musical instrument in existence. In the Pianorad one vacuum tube for each key is connected electrically with certain coils (inductances). Any number of notes can be

> played simultaneously, as on the piano or organ; unlike the piano, however, the notes can be sustained for any length of time. On the ordinary piano you strike the key and the sound dies away, in the Pianorad, the sound remains as long as the keys are depressed.[169]

Clyde J. Fitch constructed the Pianorad at the Radio News Laboratories using Gernsback's design. Fitch wrote an article giving details in the instrument's construction. From this article we see that the instrument used simple LC feedback oscillators:

> Now we come to the problem of controlling this squeal [oscillation], and making a musical tone out of it. First we connect a fixed condenser across the secondary winding connected to the grid and filament . . .; immediately the squeal becomes much lower in pitch. By connecting condensers of different capacities across the winding, the pitch of the squeal will be correspondingly varied. The larger the condenser, the lower the pitch, and vice versa.
>
> It is almost impossible to obtain fixed condensers of the exact capacities required to tune the circuit to a definite musical tone. Therefore, we connect across the coil a fixed condenser that gives a note rather near, but higher in pitch than the musical tone required; and then fine iron wires, or for that matter any small pieces of iron such as nails, are placed in the center of the windings, where the core was originally. As the iron approaches the coil the pitch of tone lowers. Perhaps the correct note is obtained with a piece of iron wire half way into the coil. Some means, therefore, must be devised to hold the iron in position.
>
> In building the Pianorad it was found that the simplest method is to fill the center holes of the windings with modeling clay, and then stick the iron wires into the clay. In this way a very gradual

> change in pitch can be made and it can be held constant at the desired value.[170]

The Pianorad had twenty-five separate speaker diaphragms connected to a single loudspeaker horn to minimize beat frequencies.

The Pianorad was first demonstrated publicly on June 12, 1926 on a concert over radio station WRNY, New York, The soloist was Ralph Christman. The instrument was used at WRNY for some time, usually accompanied by piano or violin, or both.[171]

Gernsback duly credited Lee de Forest with the invention of the basic principle used in constructing the Pianorad:

> The principle embodied in this instrument was first demonstrated in 1915 by Dr. Lee de Forest, inventor of the Audion. At that time Dr. de Forest was able to produce musical tones by means of vacuum tubes, but the radio art at that time had not progressed sufficiently to make possible the pianorad.[172]

Gernsback's instruments, as were most of the early purely electronic polyphonic instruments, were predicated on the notion of simply using one oscillating element for each note to create a polyphonic instrument.

In 1930 R. C. Hitchcock, of the research laboratories of the Westinghouse Electric and Manufacturing Company, announced the construction of an electric organ which gave a ". . . practical use . . . for the squeal of a radio tube."[173]

The organ was erroneously reported to be the first to produce music from electrical circuits, but comments such as: ". . . by regulating the pitch of the squeal, and by utilizing several tubes, each controlled by a keyboard . . . , musical tones are produced. . . .,"[174] reveal the correspondence of this instrument to earlier ones. The organ, which was not named, was played on the air for the first time on January 25, 1930, over station KDKA, Pittsburgh.

The most overwhelming examples of the "one note--one tube" principle were the electronic organs constructed by Edouard E. Coupleaux and Joseph A. Givelet. These elaborate instruments, using hundreds of vacuum tubes, were constructed during the nineteen-thirties and installed in several churches and radio stations in France. These instruments used vacuum tube oscillators generating complex waves. The following is a description of the design:

> The principle employed in the tone generators permitted the use of several different methods of tone-quality control. Each oscillator, which was an ordinary inductively coupled feedback oscillator, was adjusted to produce an almost pure sinusoidal wave-form, and harmonics were introduced by various alterations to the circuit conditions. For instance, a change in the ratio of inductance to capacitance will distort the pure wave-form and cause harmonics to appear, especially when the inductance is increased. In another method, the grid bias applied to the oscillators may be changed whereby the tubes are caused to operate over different portions of

> their characteristic curves, again producing waveform distortion. Filter circuits for regulating the harmonic amplitudes may be used, and by slightly shifting the frequencies of some of the notes, the tone quality will be affected by reason of the altered beats between the harmonics. The possibility of producing synthetic tone qualities by means of harmonic synthesis was also realized.[175]

The Coupleaux-Givelet organs used many such vacuum tube oscillators with associated filtering circuitry. The organ installed at the Poste Parisien broadcasting station had seventy-five timbre combinations, and used 400 triode tubes. Miessner's comments on the Coupleaux-Givelet organ once again confirm the relationship between this polyphonic instrument and the earlier monophonic instruments:

> The Coupleaux-Givelet Organ , like de Forest's plan, utilizes one audio-frequency oscillator tube for each note of the musical scale. For each different timbre they use a complete series of such oscillators followed by an amplifier and speaker. Thus, for ten different timbres through a pitch range of 70 notes, they use 700 oscillator tubes, and ten amplifier and reproducer outfits. . . .[176]

Considering this tendency for inventors to expand upon principles used in monophonic instruments, it was perhaps inevitable that a polyphonic instrument would be constructed using the heterodyning or "beat frequency" method made popular by Theremin's and Martenot's monophonic instruments. Such an organ was built by the French firm, Le Materiel

Telephonique around 1930.[177] The heterodyning method, applied to a polyphonic instrument, requires extremely stable oscillators; for this reason this particular instrument used crystal-controlled oscillators. The design used one radio-frequency oscillator operating continuously at a fixed frequency. Similar oscillators were adjusted to frequencies differing from the fixed frequency by suitable amounts to produce the equitempered scale, by means of heterodyning (producing difference tones). The latter oscillators were set in operation by depressing corresponding keys on the organ manual. The oscillators were designed to be high in harmonics, and consequently, the audible beat notes were, also. The outputs of the various oscillators were passed through a set of tuned detector tubes which allowed for control of harmonic content. Little is known about this instrument's subsequent history.

The organ designed by Oskar Vierling and Winston E. Kock, around 1930 in Germany, represents a departure from the use of vacuum tube oscillators. This instrument used an abridged gas-tube discharge circuit which functioned as a sine wave oscillator. The design is similar to that used in Trautwein's monophonic instrument, the Trautonium. Kock explains the desirable features of such a design, and explains the principle of the circuit:

> The majority of sine wave generators now in use have various disadvantages and limitations. Vacuum tube generators have the weakness of pitch instability, whereas tuning fork generators require an extensive filter system to produce a pure sine wave. The oscillator about to be described in very simple and convenient and overcomes to a large extent the difficulties hitherto experienced.
>
> The circuit employed is that of the inductive glow discharge oscillator . . ., and consists of the well known intermittent glow discharge circuit [as in the Trautonium] but with an inductance inserted in the condenser arm. Oscillations take place due to the difference between the striking and extinction potentials of the glow discharge tube. . . .
>
> . . . .
>
> The insertion of an inductance tends to prevent the sudden changes of current in the condenser arm, and . . . at the frequency of resonance, and discharge lasts throughout practically the entire cycle, so that even in the discharge tube a fairly sinusoidal current wave exists. The arm current is affected even more so, and the voltage across the condenser possesses a remarkable purity.[178]

The Vierling Organ evidently was successful, for we find a description of this instrument (or its descendant) in a recent edition of Alan Douglas' The Electronic Musical Instrument Manual.[179] This discussion indicates that the present-day Vierling Organ uses twelve master oscillators for the top or 1-foot octave, all other pitches being derived by frequency division.

Another instrument that used the frequency division concept was the Hammond Novachord, which was capable of producing both percussive and sustained tones with a controllable range of attack and decay characteristics. The Novachord was introduced in 1939, about the same time as the monophonic Hammond Solovox, and operated on similar principles. Alan Douglas explains:

> The instrument operates on a similar principle to the Solovox, using a series of twelve oscillators of fixed frequency for the top twelve semitones, and a series of frequency dividers for all the lower notes. Double triode valves [tubes] are used in the oscillators, the upper section being connected in a conventional tuned circuit which can be adjusted for pitch, whilst the lower section forms the vibrato device; a vibrating reed alters the grid bias of this section, altering the gain in a periodic manner.[180]

Further details of the oscillator units can be found in a descriptive article by Frederic D. Merrill, Jr.[181]

The Novachord had particularly interesting envelope and timbre controls. The control board on the front of the instrument had many switches which varied the timbre and attack, creating imitations of instruments and other unusual sounds. When the Novachord was introduced in February, 1939--in the Ritz Carlton Hotel, New York--a reviewer wrote:

> Hammond dislikes having his Novachord called an "electric orchestra," despite the fact that its orchestral talents are considerable, and for this reason: the Novachord not only imitates known instruments but produces sounds which have no equivalent on the conventional palette. As for the success of its imitations, the piano tone sounds

> very similar to a piano over the radio. And its imitation of the harpsichord led one noted pianist, Moriz Rosenthal, to say that he considered it better than some actual harpsichords he had played on.[182]

The following May a Novachord orchestra was established, under the direction of Ferde Grofe, as a daily feature of the Ford exhibit at the New York World's Fair. Nicolas DeVore made some interesting observations:

> It is going to be about as easy to keep it Novachord out of EVERY orchestra as it would be to bar a sax from a jazz band. It isn't only that it produces several instruments for the price of one, but it produces tones that no one ever imagined outside of a Thorne Smith alcoholic extravaganza; and in a potential variety that will afford an undeveloped realm of discovery to keep the intrepid tonal explorers busy for the next year to come.[183]

The Novachord orchestra consisted of the following personnel:

> . . . Vera Brodsky, Gladys Stevenson, and John Finke, Jr. at the Novachords; Collins H. Driggs, at the Hammond Organ; with Ferdie Grofe himself supplying one section of his theoretical orchestra on the Novachord from which he conducts. The music is all arranged by him. At the opening he had a repertory of forty numbers, the fruit of three months of work.[184]

Although the Novachord had only twelve master oscillators, the frequency divider circuits and envelope controls and amplifiers necessitated the use of many more tubes. The instrument used a total of 163 vacuum tubes. Frederic D. Merrill discussed traditional problems with such vacuum-tube instruments:

> Vacuum tube oscillators for producing musical tones have been suggested many times, but the problems of frequency drifting, timbre variety and proper amplitude-time starting and decaying characteristics to simulate organ or percussive qualities for a keyboard chordal instrument have necessitated the use of many tubes in a tremendous complexity of circuits. Consequently the design of a practical commercial model of small size and low cost that could be made in mass production represents an outstanding achievement in electronics engineering.[185]

Unfortunately, the Novachord suffered from some of the problems mentioned above. Mr. Robert J. White, a long-time employee of the Hammond Company commented on the technical and musical problems of the Novachord:

> The Novachord made beautiful music if played well, but it was not well adapted to either an organist's style or a pianist's style. Thus is required development of a specific style, which not many musicians were prepared to do. It also had technical problems, requiring frequency adjustments to keep it operating, chiefly because the frequency dividers and electronic components before the war were not nearly as good as those available in later years. We [Hammond Co.] could have revived it after the war, and could have made it much better in light of available technology at that time, but sales had been disappointing and so it was not considered a good commercial product.[186]

These comments again confirm the difficulties encountered in the production of a purely electronic instrument prior to World War II; evidently electromechanical tone generators were more stable and economical than tube oscillators up to that time. The War, of course, interrupted the production of electronic musical instruments to a great extent. Due to the development of the electronic industry, the post-war market for electronic instruments marks the development of purely electronic devices almost to the exclusion of earlier electromechanical types.

Material highlighting the development of the post-war electric organ industry is readily available. Those wishing to know more about contemporary electric organ designs should consult the following sources: Robert Eby's The Electric Organ,[187] Alan Douglas' The Electronic Musical Instrument Manual,[188] Richard H. Dorf's Electronic Musical Instruments,[189] and Douglas' The Electrical Production of Music.[190]

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CHAPTER IV

ELECTRONIC MUSIC SYNTHESIZERS

Synthesis is the process of composing or combining of parts or elements so as to form a whole.[1] In general, electronic music synthesizers have been designed to give explicit control not only over the constituent elements of individual sounds, but often over the complete musical composition. Electronic music, in part, represents an attempt to transcend human performance limitations. Synthesizers and tape manipulation techniques are the outgrowth of this desire to extend the possibilities of music beyond human neuro-musuclar capabilities toward the limits of human perception of sound. This is one of the fundamental distinctions between the raison d'etre for synthesizers and other electronic instruments that were designed for "different" or "better" performances in the concert tradition. Use of the synthesizer departs from traditional musical arrangements in which instruments are played in aggregate to realize a notated musical score. With synthesizers, the composer and performer are the same, and the need to provide notation--a means of communication between composer and performer--disappears.

The composer using the synthesizer, however, cannot escape the fact that hearing music is dependent on the passing of time. Max Mathews, pioneer of sound synthesis using the digital computer, notes:

> Many tasks now done by people are best described simply by one or more functions of time. To list only a few examples, the control of machine tools, the control of plants such as rolling mills or chemical processes, the control of the body itself, speaking and playing music can all be characterized by a suitable set of time functions.[2]

Ostensibly, any device that controls functions of time could be modified to make music. In order to restrict the scope of this paper, the author will discuss those devices that have been built specifically as musical instruments. Adaptations of general-purpose devices, such as the digital computer, will be excluded. There is no implication that the techniques ommitted are not important--some are so important they warrant a more complete discussion than is possible here. Computer technology, in particular, is becoming important in electronic music, and will account for a great deal of music in the future. References for topics excluded, such as hand-drawn sound on film, classical sound electronic music studio techniques, digital sound synthesis, and digital-analogue techniques, will appear at the end of the chapter.

The synthesist-composer does not rely on performers to control functions of time in his composition. He uses mechanical or electronic aids to facilitate composition.

Mechanical aids to musical performance are very old, beginning about 1000 A.D. with the invention of clockwork. These include the barrel organ, music boxes, Maelzel's mechanical orchestra, and the player piano.[3] The first electronic coded-performance devices used perforated paper rolls similar to the player piano. This made it possible to encode an *entire* composition, store it on paper tape, and play it back at another time. Typically, the coded-performance synthesizer uses a mechanical paper tape reader to key electrical circuits--the perforated tape merely *controls* time functions in circuits responsible for creating and modifying sound.

Recently, the multi-track audio tape recorder has emerged as a powerful tool for electronic music composition. This audio tape does not control circuits, but stores the musical sounds as patterns of magnetization of the tape. This tape recorder is often used in conjunction with the relatively new "voltage-controlled" synthesizers developed during the 1960's. Unlike some coded-performance synthesizers, however, a complete composition is rarely realized with one "pass" of the tape. Rather, a single line of music is recorded, the tape is rewound, and another line is played onto a separate "track" while listening to the first, making synchronization possible. This technique has been used in the "switched-on" albums such as Walter Carlos' Switched-on Bach[4] and Gilbert Trythall's Country Moog.[5] The technique is sometimes used in the production of avant-garde electronic music.

The modern synthesizer partially owes its existence due to some early experiments with the tape recorder. Tape recorders were used around 1950 to create Musique Concrète,[6] a music in which natural sounds are recorded, modified and distorted, spliced into montages of sound, and played on tape recorders. Electronic Music,[7] using the same tape manipulations, but using electronic oscillations as sounds, originated in Cologne a few years later. In the early electronic music studios, composition was done by tape editing and mixing, using sound sources or sound modifiers such as audio oscillators and generators, filters, envelope generators, amplifiers, white noise generators, and ring modulators. These instruments, with a tape recorder, constitute what is now known as the "classical tape studio." The modern synthesizer is a logical outgrowth of this particular kind of facility for creating tape music. Gilbert Trythall has remarked that

> A synthesizer is a combination instrument consisting of most of the instruments found in a Classical Studio designed to be electrically compatible with each other and offering maximum opportunities for the interconnection of the instruments. The independent units of synthesizers are called modules.[8]

For the purposes of our discussion, then, synthesizers are of two basic types: the older encoded-performance instruments, and the voltage-controlled synthesizers that arose from the classical studio concept.

The earliest successful electronic coded-performance instrument was demonstrated by Edouard E. Coupleux and Joseph A. Givelet at the Paris Exposition of 1929.[9] This instrument consisted of four monophonic L-C oscillators under control of coded paper tape, using a pneumatic tracker bar similar to a player piano. This _Automatically Operating Musical Instrument of the Electric Oscillation Type_ had features providing automatic control of (1) pitch; (2) volume; (3) enveloping of amplitude _and_ frequency; (4) tremolo; (5) timbre, by modifying the output filter; and (6) plectrum sounds, creating mandoline effects. Most of these control features were accomplished through the use of bellows that moved coils into relative proximities to induce different voltages. The patent specifications give complete details.[10]

In 1936, Leonce Lavallèe patented a simple coded-performance instrument using photoelectric translation of engraved grooves; another version used paper rolls having a varying width or varying position of conductive ink read by a series of brushes. Lavalèe conceived of the sonotheque, or "sound library," consisting of suitable media (paper, wax, foil, disks) on which recordings of various instruments, noises, or voices could be made using any known transcription method. Construction of hypothetical instruments using sine wave synthesis was also mentioned.[11] Lavallee's sonotheque concept was realized by the Musique Concrète group (Pierre Schaeffer, Pierre Henry, and others) in Paris during the early 1950's. Their library includes recordings of "sound objects" such as the falling of a drop of water, the sound of a gong without the impact by which the sound is produced, and the click of a Chinese block.[12]

While many electronic musical instruments have been invented due to the interest and curiosity of those outside the music industry, some instruments have been built for the express purpose of realizing specific compositional goals.

This was the case with the Cross-Grainger Free Music Machine, designed around 1944 by Percy Grainger and a young scientist named Burnett Cross.

In 1899, Grainger began his first experiments designed to free music of the pitch and rhythm limitations of traditional Western music. He conceived of a "beatless music" including "non-harmony," "gliding tones," and complete independence of voices.[13] While Grainger wrote his better-known traditional works, he began to sketch ideas for this envisioned "free music." In 1937 he experimented with the Theremin, but felt that the instrument provided only a partial solution, since it offered limited control of rhythm.

Grainger's first collaboration (1944) with Burnett Cross produced a unique, but cumbersome, instrument that fulfilled many of the desiderata of free music. The instrument consisted of two parts, a set of oscillators, and a mechanism that moved a large roll of control paper--the "score." Because of the desired musical results, controls were somewhat atypical. The pitch and loudness were varied by the elevation of control rods connected to oscillators and amplifiers. On the other end of the control rods, thin moving wheels fit into "kangaroo-pouches" formed by sewing colored paper onto the main paper. The graphs cut on the colored paper caused the shafts of the wheels to ride the top edge of the graph and follow its pattern--thereby modulating the oscillators and amplifiers. Grainger and Cross used large sheets of brown paper with one-half inch representing a half-tone; further subdivisions made microtones possible. Rhythm was calculated and controlled by horizontal measurements; rests were achieved with contact breakers. Due to the difficulty of producing intervals without glissando, the inventors built a supplementary device that keyed a reed-box, with reeds tuned in eighth-tones. The principle was the same as the familiar player-piano roll.

Richard Franko Goldman commented, in 1955, on Grainger's intentions, and uses of the instrument:

> Grainger emphasizes that his whole concept of "free music" is evolutionary, and that it has a direct connection with existing music, which it is intended to supplement and extend. To illustrate his thesis, he is at present writing graphs for selected passages from Wagner (opening of Tristan), Grief, Scriabin, and other composers. Among the graphs are also excerpts from Cyril Scott's *Quintet*, which employs gliding chords, and Arthur Fickenscher's *From the Seventh Realm*. Of his own compositions, Grainger has so far graphed only a few experimental sketches. These have been heard only by a few friends, but it is hoped that the instrument will be sufficiently perfected, and the "repertoire" sufficiently demonstrable before very long, so that it can be seen and heard by interested musicians. Grainger feels that all of this is still very much in the stage of development, and he is not impatient. He insists also that this electronic realization of his very early hopes is not an end

> in itself; it is a possible adjunct to note-composition and live performance, but not a substitute.[14]

This first instrument, however, suffered from several defects, including extreme instability of the vacuum tube oscillators. A more practical version was designed in 1951 to alleviate these problems and provide a more potent instrument. The improved instrument used pitch and volume control graphs painted on bands of a five-foot wide roll of clear plastic. As these graphs moved over control slits, they varied the amount of light that reached photoelectric cells controlling pitch and loudness. Unusual musical scales could be attained by placing tuning sticks over an arbitrary portion of the pitch control slit. The narrower the tuning sticks, the smaller the scale intervals could be. A comment by Burnett Cross underscores the distinction made between the Free Music Machine and other instruments: ". . . we did not spend time developing features that would be of secondary importance to a composer. Grainger wanted a composer's machine, not one for the concert hall."[15] Although the Free Music Machine was designed to control only pitch, duration, and intensity; the expressed desire to build a composer's machine places the device in the general category of the synthesizer--rather than a performance instrument.

A much more elaborate coded-performance instrument was patented during the time of the first collaboration of Grainger and Cross. The Apparatus for Automatic Production of Music[16] was developed in 1945 by John Hanert, for the Hammond Organ Company. This instrument, also known as the Hanert Electrical Orchestra, involved a most unusual adaptation of principles used in coded-performance electronic instruments. Hanert reversed the typical design of using a stationary reader with moveable paper tape. In his design, a large table held cards on which marks capable of conducting electricity could be made. A scanning apparatus was mounted on a motor driven carriage fitted with flanged wheels, and the carriage was made to move over the notation cards. Pairs of brushes then made contact through the medium of the conductive marks on the cards, keying and controlling circuitry responsible for various musical functions. Another scanner controlled overall volume, timbre, and other functions having a longer time base. The secondary scanner was incremented on command from the primary scanner.

The Hanert Electrical Orchestra was an extremely complex instrument with facilities for octave coupling; generation of percussive sounds, such as xylophone, piano, drums, using a random frequency generator; timbre control; and control of accelerando and decelerando by changing the speed of the carriage motor. While the mode of operation may seem clumsy, it offered certain advantages. In the first place, it would be easy to hear any combination of pitch, loudness, timbre, etc., by merely moving the scanning apparatus past the notated cards. Editing would present no problem whatsoever, since the conductive marks could be made with a graphite pencil--and easily erased. Entire cards, which were approximately 11 by 12 inches, could be replaced if necessary. Using these techniques, the composer or arranger could try many different combinations easily; furthermore, compositions could be stored or worked on intermittently.

Hanert's comments sound remarkably similar to some used today in support of electronic music:

> The composer ultimately usually has but slight control over the instrumentation employed by the orchestra and it is only after . . . tedious and time consuming steps have been taken and the orchestra ultimately renders the composition that the composer can actually audition his composition. . . . . . . it is seldom that a recording represents the closeness to perfection which is anticipated by the composer and conductor, ...
>
> In the method and apparatus of this invention the composer, arranger, or conductor has at his command means for controlling the quality of each note, its intensity, intensity envelope, the degree of accent, duration, and tempo without necessarily affecting any other note or tone of the composition. He thus has under his control, within the limitations imposed by the apparatus as a whole, facilities for

> producing, under his sole control, any of a substantially infinite variety of renditions of a composition. (Italics mine.)[17]

The final comments underscore Hanert's desire to construct a system of instruments to give the composer control over the complete fabric of the musical composition. The author believes that this sentiment has shaped the development of synthesizers available today. Hugh LeCaine stated:

> The operation of Hanert's electronic music synthesizer was based upon the breakdown of a tone into characteristics such as frequency, intensity, growth, duration, decay, portamento, timbre, and vibrato.[18]

Although Hanert's synthesizer was not economically feasible, it should probably be considered the earliest complete synthesizer--a device by which music is intentionally reduced to its constituent elements and reassembled into coherent musical structures.

The devices discussed so far relied on mechanical means of "playing" the composition produced. During the late 1940's Osmond Kendall, a Canadian, invented the Composer-Tron, a synthesizer that relied, in part, on electronic devices to facilitate performance. This instrument was developed by the Canadian Marconi Company during the early 1950's. The Composer-Tron made use of a cathode-ray tube to read sound envelopes drawn by hand on the face of the scope. These envelopes could be applied to the output of an electronic generator that created waveforms associated with different timbres. Rhythmic sequences could be controlled by marking a special cue sheet consisting of a strip of film. Comments by Alan Phillips seem familiar:

> At present, the composer writes his mental symphonies as black symbols on lined white paper. He has no way of knowing whether they're just what he had in mind. Months or years may pass before he hears them played by a symphony orchestra. Not uncommonly, he never hears his best work.
>
> . . . .
>
> With Kendall's grease pencil, the composer can, in effect, draw the grooves in the record. Working with a composer-Tron . . . he can walk out of his study . . . with his recorded composition under his arm.[19]

Lou Applebaum, Hollywood Composer, worked with the Composer-Tron during the nineteen-fifties. He remarked that the Composer-Tron ". . . has the same relation to conventional music that the invention of films had to the live stage."[20] He foresaw widespread use of the machine. Kendall felt that the Composer-Tron would eventually become a popular instrument in the home. Although the Composer-Tron was evidently capable of production of sophisticated music, little was heard of it in subsequent years.

Earle L. Kent introduced his <u>Electronic Music Box</u> at a meeting of the Institute of Physics in October, 1951.[21]

Kent began his distinguished career in his teens, applying for his first patent while in High School. He worked on electronic musical instruments all through college, and was probably the first to publish the use of printed circuits--using them in a version of an electronic instrument that he made during the 1930's.[22] Kent built the Electronic Music Box as a project in his spare time, without consideration of commercial possibilities. He hoped to provide an instrument of ". . . wider flexibility of performance than is possible in any conventional musical instrument."[23] It was called an electronic music box because it produced its tones automatically, using a perforated paper roll. The heart of the instrument, which could be built with several voices (channels), was a frequency changer. This device makes it possible to create a tone with a predetermined harmonic structure (timbre) and to change the fundamental frequency of this wave without changing the harmonic content. In Kent's design, a fixed 30 kilo-hertz complex tone generator interacted with the pulse frequency of the frequency changer to produce an audible sound. The principle is similar to that used in Theremin's heterodyning instruments. The Electronic Music Box was designed to give pitch control using variable resistances; slurring and enveloping controls by varying R-C circuit time constants; formant control, using resonant circuits; and control of volume and tremolo.

Kent built a demonstration circuit that was shown in Chicago at the National Electronics Conference during 1951. This attracted so much attention that the Conn Company, for which Kent was research director, became interested in the project. Unfortunately, little was done with the idea.

Although Kent's ideas were not commercialized, they were influential. Percy Grainger and Burnett Cross visited Kent in hopes that the Electronic Music Box would offer an avenue to the composition of "free music." More important, though, was the possible influence that Kent's Chicago demonstration had on the development of the RCA Electronic Music Synthesizer, a later coded-performance synthesizer. Kent writes:

> RCA was working on a music "synthesizer" at the same time I was working on my "Music Box." Dr. Harry Olson was very [interested] in my demonstration in Chicago and he made . . . changes in the RCA synthesizer after that. I suspected my instrument influenced the change, for my approach was simple, and the RCA approach was quite complex and tedious to use when they started. After my demonstration the RCA system was changed to be more easily used.[24]

The RCA Electronic Music Synthesizer is the best known coded-performance electronic musical instrument. This instrument was built in two versions: the Mark I, built during the early 1950's; and the Mark II, which has been housed at the Columbia-Princeton Electronic Music Studios since 1959.

The RCA Synthesizer was constructed by a group of engineers headed by Harry F. Olson and Herbert Belar; the device has sometimes been called the "Olson-Belar Synthesizer." In an article by Olson and Belar we find remarks indicating the intended scope of the device:

> It is the purpose of this paper to describe an electronic music synthesizer capable of producing any predetermined musical tone and any combination of series of musical tones combined with a system for translating the symbolic notations of a musical composition into the corresponding tones, and means for recording these sounds on a phonograph record.[25]

The RCA Mark I Electronic Music Synthesizer appears to be the first complete device to use the descriptive word "synthesizer" as part of its name. This implies a more thorough, and conscious attempt to reduce music to its constituent elements than that managed by earlier machines. Comments by Olson and Belar confirm this approach:

> The properties of a musical tone are frequency, intensity, wave form, and time. It is more convenient to describe the properties of a tone in terms of frequency, intensity, growth, duration, decay, portamento, timbre, vibrato, and deviations. If these properties of a tone can be completely specified, the tone can be completely described. The electronic music synthesizer described . . . is based upon the breakdown of a tone into these characteristics.[26]

The programming input of the Mark I (and the later Mark II) consisted of binary code instructions which specified the musical properties listed above. On the Mark I this code was punched on a fifteen-inch wide paper roll, using a "keyboard" consisting of several vertical columns of three or four keys each. Each set of four keys gave sixteen binary possibilities. These numbers were used to specify frequency, octave, timbre, enveloping, and volume in each of two channels. The Synthesizer read these numbers as the rows of holes passed under a series of brushes. The brushes were electrically connected, through relay trees, to portions of the synthesizer responsible for controlling the various musical functions. Each brush was equipped with springs, arranged so that the brush did not break contact between holes; a series of holes could then provide a continuous tone, for instance. The output of the synthesizer was then recorded on disk, using a Scully lathe and turntable that was mechanically synchronized with the motor of the paper tape reader. While the Synthesizer could produce two simultaneous voices, in practice only one was synthesized. Olson explained:

> In general, due to the characteristics of most musical sounds, the system is actually limited to a series of single tones. That is, the system can simulate any single wind instrument, . . . or one finger playing of a keyboard

> instrument, ... Thus it will be seen that in order to simulate an orchestra, each individual instrument must be coded and recorded separately and then the group of instruments combined.[27]

This mode of operation distinguishes the Mark I from earlier coded-performance devices such as the Hanert Electrical Orchestra, which immediately realized scores of lesser sophistication. On the other hand, the mode of combining monophonic lines bears an obvious relationship to current multi-track tape recording techniques. Olson explained the method used with the Mark I:

> The sixteen-inch disk record can accomodate six three-minute recordings. After six complete recordings have been made, which represents six different musical renditions, the six recordings are combined into a single recording by means of the double turntable recording system. . . .
> . . . it is possible to record 36 individual records [by repeating this step].
> In the next step, the record on the upper turntable containing the combination of 36 individual records can be transferred to the lower turntable and the recording process repeated.
> . . . In this way any number of individual records can be recorded.[28]

The RCA Mark I was a complicated instrument capable of producing a great variety of sounds. Only a synopsis of the basic design features, as reported in Olson and Belar's extensive article,[29] will be given.

The fundamental frequency source consisted of twelve electrically driven tuning fork oscillators in the range of

$F_5\#$ to F_6 in the equitempered scale. Frequency dividers and multipliers were used to produce rectangular and sawtooth waveforms; an octave selecting system was used to provide frequencies over a seven octave range. A white noise generator was also provided.

Amplitude control (attack and decay) was obtained by switching in various R-C circuits having different time constants. Volume control was attained by controlling the voltage applied to grids of a vacuum tube push-pull amplifier.

Means were supplied for portamento with a rather complicated comparison system in which the frequency of an oscillator was adjusted to the input frequency. If the input frequency moved discretely, the output frequency changed in a controllable, continuous manner.

Timbre control was accomplished with the use of variable low pass and high pass filters, and band pass and band reject resonator chains.

There is some confusion as to the exact intentions that RCA had for its Synthesizer. In 1955, Olson explicitly discussed commercial applications:

> One of the uses foreseen for the music synthesizer is to make music for sale in the form of phonograph records. To make an artistic record, or a hit, novelty or technical excellence alone is not sufficient. There are other ingredients, many of which

> are intangible. However, the synthesizer will facilitate the production of such a hit. For example, the synthesizer can produce any kind of sound that can be imagined. Then if a person can image a hit, then the synthesizer will facilitate the production of the hit.[30]

Early applications seem to hint at the synthesis of existing instruments. The RCA Synthesizer demonstration record[31] (1955) presented examples in the "style" of many acoustical instruments.

By 1960, due, in part, to the uproar caused by the American Federation of Musicians, Olson eschewed synthesis of existing instruments:

> Except from a purely scientific viewpoint there is no interest and no desire to create music which can be produced by conventional means. The added effort and the new employment of musicians capable to perform synthesis is warranted only if it can produce something new or better in the art of music.[32]

About this time, RCA abandoned any projected commercial ventures and donated the expanded and modified Mark II Synthesizer to the Columbia-Princeton Electronic Music Studio. Articles by Olson[33] and Milton Babbitt[34] highlight modifications made in the creation of the Mark II. The most important modification was the change from disk to tape recording, making use of a photoelectric system to handle synchronization. Also, tuneable oscillators were added, expanding the temperament possibilities beyond the restrictions of the equitempered scale.

The Columbia-Princeton Studio rapidly developed into a major center for the production of electronic music. Prominent composers who have used the Mark II include Vladimir Ussachevsky, Otto Luening, Milton Babbitt, Charles Wuorinen, Halim El-Dabh, Bulent Arel, and Mario Davidovsky. Important compositions having passages realized on the Mark II include "Gargoyles," by Luening; "Creation-Prologue," for multiple choruses and electronic accompaniment, by Ussachevsky; "Stereo Electronic Music No. 1," by Arel; "Leiyla and the Poet," by El-Dabh; "Electronic Study No. 1," by Davidovsky; "Composition for Synthesizer," by Babbitt; and "Times Enconium," the 1970 Pulitzer Prize Winner, by Wuorinen.

Milton Babbitt, in particular, has found the Mark II to be a useful tool to create his mathematically and musically complex compositions. His comments emphasize the capabilities of the Mark II:

> Clearly, any rhythmic structure can be secured, in the sense of both linear rhythm and ensemble rhythm. Any frequency or frequency collection is available, be it a particular division of the octave, or a distribution of frequencies none of which are in an octave (including multiple octave) relationship to one another. . . . Any mode of succession from event to event can be secured, since any envelope and intensity values and patterns can be achieved.

> The source signal need not be the saw-tooth or the white noise provided within the Synthesizer; any "external" signal--live or recorded--can be fed into the Synthesizer, bypassing the frequency and octave sections and controls, to be processed by the other sections as directed by the coded program control.[35]

Babbitt feels that the Mark II is a unique device capable of explicit structuring of sound events in time; hence, the Mark II has not been superseded by the synthesizers developed more recently. He also recognizes that it would not be neither possible nor productive for a large number of composers to work with the device. He outlined the reasons the use of the Mark II will probably be limited to a few composers:

> You can't take the experience of this machine in any specific way to the experience of any other machine.
>
> The other thing is, that it is so tedious, and demands that you learn so much before you can even make your first combination of sounds.[36]

Because of these restrictions, Babbitt recommends that young composers learn the general principles of either the classical tape studio, or digital synthesis.

Because of the growing interest in electronic music, more mobile and less complicated devices for the production of electronic music have been developed. The first such instruments were special purpose devices designed to be used in classical tape studios.

One of the first instruments built specifically for an electronic music studio was Friedrich Trautwein's Monochord, which was based on the older Trautonium. Trautwein explained the circumstances of construction, and distinguishes the Monochord from its predecessor:

> In 1952 the electronic music studio of the Cologne Radio Station, which was designed by F. Encke largely on the basis of suggestions made by W. Meyer-Eppler, commissioned the present author to develop and design an electronic sound producer which was to be based on experience with the Trautonium but was to differ from it by putting more emphasis on the question of "original composition technique." In order to express this idea clearly in the name as well, the term "Trautwein Electronic Monochord" was chosen for the Cologne instrument.
>
> While in purpose, design, and actual use, especially in the hands of O. Sala, the Trautonium is an instrument which permits a highly artistic rendering of music, enabling the player to give a new artistic performance each time the same piece of music is played over again, original music is a workshop operation which may require considerable time. Hence, the element of spontaneity is absent. Therefore, the design of a sound producer for original composition need not have any special playing aids to facilitate rapid changes of tone colour and register without interfering noises.
>
> Nor were the subharmonic mixed stops, which are characteristic of the Trautonium, incorporated for the time being, since the principle applied for original composition, namely that of superimposing recordings of several voices played separately on a single sound track, permits the production of such effects, although correspondingly more time is

> required. At the same time it should be realized that a device equipped with all the aids needed for a highly artistic rendering of music is also well suited for use in an electronic studio and would certainly not be a disadvantage. However, owing to limitations of time and price, the project was confined to minimum expenditure needed for the task.[37]

The Monochord is a two-voice instrument using variable pitch band-manuals similar to those found on the Trautonium. Band-pass and band-reject filters were provided to alter timbre. Volume and enveloping are controlled by a pedal and a pressure-dependent resistance located under the playing manual. The Monochord is essentially a Mixture-Trautonium lacking more sophisticated performance controls such as register and timbre pedals.

Another instrument designed for the Electronic Music Studio in Cologne was the Melochord by Harald Bode. Bode has been involved in the development of several devices for use in the electronic music studio; his ring modulators and frequency shifters are presently in use in many electronic music studios.

The Melochord is a keyed instrument with two independent monophonic playing ranges, covering seven octaves. An interesting feature is a "traveling formant" fil r that can be tuned with the pitch. Using this feature, one can play pitches on one keyboard and alter timbre using the other. The instrument also has a generator of white noise.

Bode's comments reveal that the Melochord was designed specifically for studio use--not live performance:

> . . . the task of opening up an absolutely new musical field by the use of electronic sound producers in conjunction with known instruments, aids and methods of broadcasting and telecommunication technique, goes beyond the narrow bounds of conventional interpretation of music. With a view to accomplishing such a task, the Melochord of the NWDR Cologne was developed and has become an indispensible part of the Studio for Electronic Music.
>
> The basic idea in designing this instrument was to have outside the instrument the controlling apparatus for all the sound parameters which may be represented by known aids, while the latter should contain only the elements which are characteristic of it.
>
> . . . .
>
> All additional aids by which it is possible to produce sounds in great variety are not discussed here, since they have been described in great detail in the literature. These aids include above all the utilization of magnetic tape techniques, ...[38]

In the United States, Raymond Scott has developed many devices for the electronic music studio. After a distinguished career as a well-known composer and band leader, during the 1950's Scott turned his attention toward producing sounds electronically. He soon constructed a very elaborate studio for the production of electronic music and Musique Concrete, and began to create sounds for commercials, ballet music, and other compositions. Among other things, Scott developed and used devices such as triggered delay circuits and rhythmic sequencers several years before they appeared on present-day synthesizers.

Scott's latest invention is the Raymond Scott Electronium, a device capable of producing and controlling several voices simultaneously. Although technical details are not available, this author assumes that the device uses some form of memory system in order to control analogue devices (oscillators, filters, amplifiers, etc.).

Scott emphasizes that the Electronium is a composing machine that is not played but "guided" by manipulation of its myriad switches and knobs.[39] Having heard what Scott called a "limited version" of the Electronium, the author was impressed with the rather astonishing changes of sonority and texture that the instrument produced instantaneously. It is possible that the Electronium may emerge as a significant tool for the rapid composition and realization of complete musical works.

The development of the portable transistorized synthesizers, e.g., Moog, Arp, and Buchla, has occurred primarily in the United States. The versatility and ease of operation of this type of instrument has contributed to the proliferation of electronic music around the world.

Several features distinguish the transistorized synthesizer from earlier electronic instruments. First, the synthesizer is modular; that is, it consists of a collection of modules which may be reassembled instead of remaining in a fixed arrangement. Second, several of the modules are "voltage-controlled"; this means that the function of a given module, such as amplification, filtering, or frequency generation, can be regulated by applying a voltage to a control input on the module.

Some of the modules found on the synthesizer are common to all electronic musical instruments. For instance, almost all electronic musical instruments have (1) audio signal generators or oscillators; (2) signal modifiers, including loudness pedals, attack controls, and timbre regulators; (3) and performance controls, such as a keyboard. In addition to these, synthesizers often have special modules such as a ring modulator, white noise generator, timing units, and sequencers. Also, synthesizers usually have some sort of modifiable routing system used to "patch" the modules together into usable configurations.

A modular electronic music system--a synthesizer--is composed of modules designed to generate or process certain classes of signals. Audio signals, the basic sounds used in electronic music, are produced by various sorts of generators (sine, square, sawtooth, harmonic, noise), or are routed to the synthesizer from external sources (tape deck, microphone, radio).

Control voltages are used in conjunction with voltage-controlled modules to determine frequencies, amplitudes, filter cutoff frequency, envelope characteristics, and other parameters. Control voltages are generated by keyboards, ribbon controllers, X-Y controllers, programmable voltage sources (sequencers), and envelope generators. An envelope generator, for instance, generates a slowly-varying non-repetitive voltage that may be used to impart an envelope to a steady signal. If this envelope is applied to a signal passing through a voltage-controlled amplifier the amplitude characteristics--rise time, duration, and decay--of the signal will be controlled. Other musical characteristics may be controlled similarly.

Triggers, or timing pulses, are used to trigger notes, open electrical gates, or initiate chains of musical events. Triggers originate from keyboards, ribbon controllers, programmable sequencers, and pulse generators. Timing pulses, or triggers, are often used to initiate the operation of an envelope generator.

The modules of a synthesizer can be connected in many different ways; this provides a versatility and control over sound that was not possible with many previous electronic instruments. Gilbert Trythall has described the functions of individual modules and discussed basic interconnections in a recent manuscript.[40] This author will give only an overview of the possibilities.

The first requirement for the creation of a sound is the generation of an audio signal. In the simplest configuration this signal may be amplified and recorded--producing a continuous sound. Most synthesizers are designed for _subtractive synthesis_, using complex waves that are modified by filters of various kinds. _Additive synthesis_--the control of timbre by governing the amplitude of sine waves--is theoretically possible on some synthesizers, but is rarely used, due to technical problems such as oscillator instability. A typical synthesizer configuration uses a complex wave signal that may be modified by modules such as filters, including formant, high-pass, low-pass, and band-pass types; a ring modulator; and reverberation devices. The basic audio signal is transformed in timbre but is not "enveloped"; that is, the sound remains uncontrolled in frequency and amplitude.

The frequency, amplitude, and timbre may be controlled by manually adjusting the controls on the various modules used. However, control voltages are used in order to generate precise, dynamically varying sounds.

The audio signal passes through modules whose characteristics may be regulated by applying a periodic repetitive control voltage or a non-repetitive control voltage generated by an envelope generator. The signal may then be altered in frequency, amplitude, or harmonic spectrum by changing the characteristics of the voltage applied to the oscillator, amplifier, or filter concerned with the signal. For instance, if a subsonic (6-8 hertz) sine wave were applied alternately to the control inputs of the voltage-controlled oscillator, voltage-controlled amplifier, or voltage-controlled low-pass filter, the musical results produced would be vibrato (frequency modulation), tremolo (amplitude modulation), and a "wah-wah" effect. These are examples of modulation using a repetitive control voltage. Of course, wave shapes other than the sine, or any combination of wave shapes could be used to modulate the voltage-controlled devices.

A keyboard and envelope generator is often used to generate non-repetitive voltages employed to control frequency, and amplitude (attack and decay characteristics). The keyboard is often a resistance-tapped device that outputs larger control voltages as one plays an ascending scale. The control voltages are used to modulate an oscillator; larger voltages cause higher frequencies. The keyboard also outputs a _trigger_, or timing pulse that is used to initiate the timing sequence of an envelope generator. In this way the rise time, duration, and decay of a sound may be controlled, and the sound can be initiated at a specific time. Envelopes can also be applied to voltage-controlled oscillators or voltage-controlled filters, giving an envelope or "contour" to the frequency or harmonic spectrum of a sound. Envelope generators may be used to shape repetitive control voltages. This might be done to create, for instance, a vibrato that changes in speed or width.

Combinations of repetitive and non-repetitive control voltages may be applied to voltage controlled modules. The characteristics of the modules will then be determined by the sum of these voltages. R. A. Moog has explained the rationale of voltage-controlled instruments:

> Engineers and composers now acknowledge that the consistent and systematic use of _voltage-controlled_ instruments simplifies both the generation of complex, dynamically varying sounds and the arrangement of these sounds into a composition. _A voltage controlled instrument has one or more_

> operating parameters determined by the magnitude of an applied control voltage rather than by the settings of the panel controls. It is generally easier to change a voltage rapidly and precisely than it is to reset panel controls with equal speed; also, the problems of changing the operating parameters of the instruments are reduced to the simpler problem of changing the control voltages determining the values of the parameters.[41]

Forms of voltage control have been known for some time, but the basic ideas that led to the voltage-controlled synthesizer were developed by R. A. Moog around 1964.[42] Moog had been designing electronic musical instruments (such as the Moog Theremin) since 1954, but became particularly interested in building a complete composer's instrument after discussing the matter with the composer Herbert Deutsch. After a summer's collaboration with Deutsch, and with the encouragement of Myron Schaeffer (then head of the Toronto Electronic Music Studio) Moog introduced several prototype electronic music modules at the Fall, 1964 Audio Engineering Society Convention.[43] In 1965 Moog published a description of these modules.[44] The modules were designed to be connected by patchcords--wires with a plug connected to each end.

Moog's first customers were innovative musicians who were already involved or interested in electronic music. Alwin Nicolai, New York choreographer, bought several modules in order to create electronic ballet music. Eric Siday, television and radio composer, purchased one of the earliest complete instruments. Raymond Scott, of "Lucky Strike Hit Parade" fame, was among the first purchasers of Moog equipment.

In 1968 Walter Carlos, assisted by Benjamin Folkman, synthesized ten works of J. S. Bach on the Moog Synthesizer. Carlos' album, "Switched-on Bach" (Columbia Stereo, MS 7194), created a great deal of excitement and commentary, and rapidly became the best-selling classical album of the year. The success of "Switched-on Bach" provided the impetus for the production of dozens of albums using the Moog--often in conjunction with acoustical instruments. Noteworthy among these albums is Gilbert Trythall's "Switched-on Nashville: Country Moog" (Athena Stereo 6003), which appears to be the first (1969) "pop" album that was totally synthesized on the Moog.

In 1969 Herb Deutsch and Chris Swanson appeared at the final 1969 concert of the Museum of Modern Art's "Jazz in the Garden" series. This marked one of the first times the Moog was used as a "live" performance instrument. Gershon Kingsley has also used the Moog in live performances. Kingsley's First Moog Quartet, consisting of Kenneth Bichel, Stan Free, Eric W. Knight, and Howard Salat made several concert appearances playing four Moog synthesizers.

Due partly to public acceptance of these developments, music and sound effects for television and film scores and commercials began to be electronically synthesized on a large scale.

To many, "Moog" music has become synonymous with "electronic music." There are, however, a number of other voltage-controlled synthesizers being used to create electronic music.

Donald Buchla developed the Buchla Synthesizer (later renamed the Buchla Electronic Music Box) about the same time R. A. Moog began to market his products. The Buchla is a modular electronic music system that provides modules (including voltage-controlled modules) similar in function to those common to other synthesizers. Modules are connected with banana-plug patchcords. In addition to the standard modules the Buchla has several unusual features. In general, no keyboard is used; instead, a "touch-controlled" voltage source is provided. This consists of a number of touch-activated, pressure sensitive, immovable "keys" together with two rows of associated fixed control voltage dials and two control outputs for each row. By using this "manual controller" it is possible to provide control voltages to any suitable module such as an oscillator--thereby controlling the pitch. Another important feature of the Buchla is a sophisticated Sequential Voltage Source, commonly called a "sequencer." With this device it is possible to control several parameters of a repetitive sequence of notes or musical events. Buchla is generally credited with being the first to market such a device. Sequencers are now available on most synthesizers.

The Buchla has not enjoyed the commercial popularity of the Moog Synthesizer. This is probably due to the difficulties encountered in playing "tuneful" music on the manual controller provided. The Buchla is, nevertheless, a potent instrument for the production of electronic music. Morton Subotnick's beautiful albums "Wild Bull" (Nonesuch Stereo 71208), and "Touch" (Columbia Quadraphonic M57316), were produced on the Buchla Synthesizer.

The Arp Synthesizer was introduced by Tonus, Inc., in January, 1970.[45] The Arp is a modular electronic music studio that uses a system of matrix switches to connect modules. Some models have a keyboard capable of producing two notes. Purchasers include universities, composers, and performing musicians. Paul Bley used the Arp in his album "The Paul Bley Synthesizer Show" (Milestone Stereo MSP 9033).

The growing popularity of electronically produced sounds has stimulated the development of smaller, more economical synthesizers. The Putney Synthesizer or VCS-3 (voltage-controlled studio, three oscillators), is a small synthesizer developed by Electronic Music Studios (London) Limited. The Putney was designed by David Cockerell for Dr. Peter Zinovieff, a former research geologist who became interested in electronic music several years ago. The Putney represents an attempt to provide a synthesizer priced within the range of the amateur or semi-professional electronic music enthusiast. The Putney has three voltage controlled oscillators, a noise generator, a voltage-controlled low pass filter, an envelope generator, ring modulator, reverb unit, and output amplifier with pan controls. This synthesizer uses a matrix patchboard with resistor pins; one resistor pin is placed in a socket to connect two modules.

Small synthesizers such as the Putney are finding their way into the public schools. The Electrocomp Synthesizer is a small synthesizer that was constructed expressly for public school use. Project "PEP," Pilot Electronic Project in Music Education, was a federally funded program in Connecticut. The PEP program, directed by Lloyd Schmidt, sought to involve students in the creation of electronic music using the classical tape studio. The project soon evolved and expanded;

a group of engineers were commissioned to build a . ıgged, portable synthesizer. The engineers, Jeff Murray, Dale Blake, Fred Locke, and Norm Milliard designed a model using patch cords. Keying was done by a four-by-four push button matrix. Voltage control on this early model was restricted to the oscillators. Later models of the Electrocomp use keyboards and have a full complement of voltage-controlled devices.

There has been a growing trend toward using the synthesizer in live performances. One of the first synthesizers to be used as a performance instrument is Paul Ketoff's <u>Synket</u>, designed around 1964. Ketoff provided a number of switches and sliders to control pre-wired signal and control voltage paths. This reduced the necessity of spending time patching modules together. The Synket also has <u>three</u> keyboards--further facilitating live performance. Ketoff described the rationale for his design:

> An important advantage of the Synket is that it permits the real-time composition of electronic music, ... The problems of composition for and playing on the Synket become, more or less, similar to those of composing for and playing on traditional instruments and, with the possibility of live performance, one avoids the discomfort of the impersonality we have felt with electronic music until now, ...[46]

John Eaton has used the Synket in numerous performance , and the instrument may be heard on Eaton's album "Electrovibrations" (Decca 710165).

Several small performance-oriented synthesizers are available today. These instruments typically have several oscillators, a filter, an envelope generator, and amplifiers. Module connection is made by switches rather than by patch-cords. Examples of this kind of instrument are the Mini-Moog, Mini-Arp, and the performance model Electrocomp.

Electronic music has become increasingly popular due to the availability of synthesizers. The synthesizer, however, will not entirely supplant earlier or traditional techniques for producing electronic music. Some techniques, such as Norman McLaren's hand-drawn music, Synthetic Sound on Film,[47] will remain specialized techniques that will not be used a great deal. The general principles of magnetic tape manipulation, however, are still used in the production of much synthesizer music. References concerning these techniques are given below.

Pierre Schaeffer recorded the history of the development of Musique Concrete in a book entitled A la Recherche d'Une Musique Concrete.[48] Jacques Poullin wrote an excellent review of Musique Concrete techniques,[49] and other articles on the subject are available.[50]

Monographs explaining basic concepts of the classical electronic music studio have been written by Andre Moles,[51] Werner Meyer-Eppler,[52] Herbert Eimert,[53] and Fritz Enkel and Heinz Schutz.[54] Fritz Enkel[55] and Alfredo Lietti[56] described some of the equipment used in early studios.

The necessity of tedious splicing of tape was mitigated somewhat by the development of the synthesizer. In the future computer technology may supplant traditional tape manipulation techniques entirely. N. Guttman, Max V. Mathews, John R. Pierce, and James Tenney were the first to demonstrate the creation of actual sounds using the digital computer.[57] More recently, Max V. Mathews and F. R. Moore have established a "digital-analogue" system for the production of electronic music. This system provides digital control of typical synthesizer modules.[58] Digital synthesis and/or control will undoubtedly become more popular when these techniques become economically feasible.

The history of electronic musical instruments is a record of diverse musical ambitions and expectations. Today's performers and composers of electronic music reflect this diversity to some extent. "Electronic music" has come to mean many things. Most present kinds of electronic music bear some relationship to instruments and ideas of the past The recent vogue of "switched-on" albums of electronic transcriptions finds its roots in the tradition of performance-oriented electronic instruments such as the Ondes Martenot. The invention of magnetic tape recording provided a significant new avenue for musical composition. But this type of electronic music was foreshadowed by composer's instruments such as Grainger's Free Music Machine, Hanert's Electrical Orchestra, and Sala's Mixtur-Trautonium.

If we adopt a narrow definition, electronic music begins with magnetic tape manipulation. Viewed from the perspective of a century of experimentation with electronic devices designed to allow greater musical possibilities, the advent of tape manipulation remains significant--but intimately related to the past. Although the development of tape music is important, computer technology may relegate magnetic tape techniques to a position of _historical_ importance. Perhaps then, _Musique Concrete_ and the classical tape studio may be viewed as another epoch in the _lengthy_ history of Man's fascination with producing music electrically.

FOOTNOTES FOR CHAPTER IV

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[3]Hugh LeCaine, "Electronic Music," Proceedings of the Institute of Radio Engineers, XLIV (April, 1956), 472.

[4]Walter Carlos, "Switched-on Bach," Columbia Stereo, MS7994.

[5]Gilbert Trythall, "Country Moog," Athena Stereo 6003.

[6]For a complete account of the Development of Musique Concrete see: Pierre Schaeffer, A La Recherche D'une Musique Concrete (Paris: Editions De Seuil, 1952).

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[8]Gilbert Trythall, Handbook of Electronic Music (Nashville, Tenn.: George Peabody College, 1970), p. 56.

[9]LeCaine, p. 472.

[10]E. E. Coupleux et al., U.S. Patent 1,957,392, May 1, 1934.

[11]Leonce Lavallèe, French Patent 806,076, Dec. 7, 1936.

[12]LeCaine, p. 474.

[13]Richard Franko Goldman, "Percy Grainger's Free Music," Julliard Review, II, No. 3 (Fall, 1955), 38.

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[17]Ibid., p. 3-4.

[18]LeCaine, p. 472.

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[26]Ibid., pp. 595-96.

[27]Ibid., p. 606.

[28]Ibid., pp. 607-08.

[29]Ibid., pp. 598-606.

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