CHAPTER 6

Early Synthesizers and Experimenters

Vladimir [Ussachevsky] often discussed with me how important he felt it was that composers in an electronic music center take the lead in imagining what they would like, as he did, and then involve the creative capacity of engineers on staff to realize that musical goal. The engineers at the Center, often of enormous talent, were there to await his directives.

—Alice Shields, commenting on the Columbia–Princeton Electronic Music Center

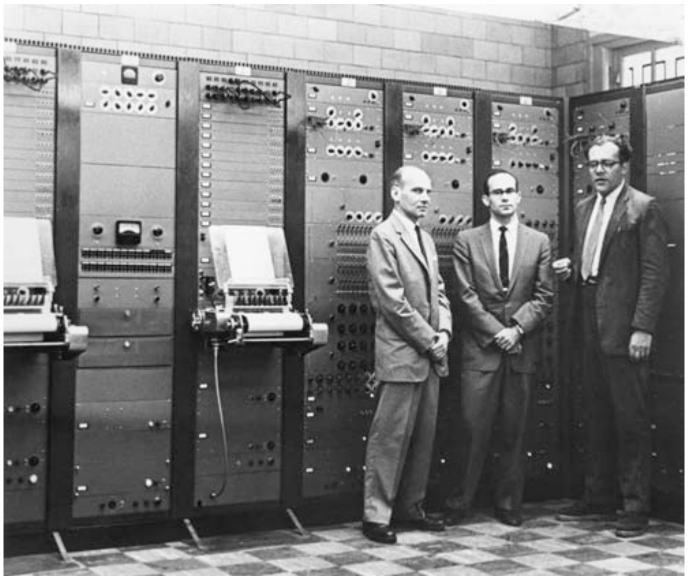


Plate 6.1 Columbia–Princeton Electronic Music Center, 1958, and the RCA Mark II Electronic Music Synthesizer. Pictured from left to right are Milton Babbitt, engineer Peter Mauzey, and Vladimir Ussachevsky. (Columbia University Computer Music Center)

Electronic music studios arose during a dramatic time of transition in the field of electronic audio technology. The coming of the transistor and especially its rapid adoption by American and Japanese manufacturers of radios, stereos, and tape recorders effectively brought the reign of the vacuum to an end by the early 1960s. Transistors were the building blocks of electrical circuitry and the first stage in the evolution of increasingly small, efficient, and versatile integrated circuits that now make up the essence of computers and most other electronic devices. Transistors can have many functions but are primarily used for amplifying signals and switching control signals. The first practical transistor was developed at Bell Labs in 1947 and was in widespread production and use by the early 1950s. Transistors had several advantages over their vacuum tube predecessors, including small size, durability, low power consumption, and a highly automated manufacturing process. Transistors could withstand shock and did not require a warm-up period like vacuum tubes. All of these factors made transistors ideally suited for use in commercial audio products, including those components commonly found in the electronic music studio.

Hobbyists took up electrical projects in increasing numbers as retail stores such as Radio Shack, Lafayette, and Heathkit competed vigorously for their business. Magazines such as *Popular Electronics* were brimming over with projects for self-taught gadget makers. One of the consequences of this Renaissance of inventing was a new generation of amateur and professional engineers who turned their attention to improving the state of electronic musical instruments. Robert Moog, Donald Buchla, Hugh Le Caine, and Raymond Scott were all a part of this new wave of inventors.

This chapter traces the development of the analog synthesizer and the building blocks of electronic music components leading to the rise of the voltage-controlled synthesizer in the 1960s.

SYNTHESIZER PREDECESSORS

The idea of the **synthesizer** is as old as Cahill's Telharmonium. The American inventor goes on record as the first to use the term for a musical instrument when, in 1896, he used it to describe his power-hungry dynamo. Cahill's idea was virtually the same as those of later inventors: use a combination of tone-generating and modulating devices to build sounds from their component parts.

During the 1950s, the best-executed design of a complete music synthesizer from the age of vacuum tubes was the RCA Mark II Electronic Music Synthesizer housed at the Columbia–Princeton Electronic Music Center from 1958. Although large, cumbersome, and difficult to master, the RCA synthesizer was a serviceable if not elegant solution for creating music electronically with the most advanced analog technology of its time. Although overshadowed after only a few years by increasingly successful experiments with computer synthesis at Bell Labs and the rise of the Moog and Buchla analog synthesizers, the RCA Mark II provided valuable insight into the problems facing composers and engineers alike in building more advanced electronic musical instruments.

RCA Electronic Music Synthesizer

The early history and origins of the **Columbia–Princeton Electronic Music Center** (see Chapter 3, pp. 93–5) form a story of intersecting desires of engineers and composers working at RCA, Princeton University, and Columbia University to establish a studio with the RCA Mark II Electronic Music Synthesizer at its core. About eight years before, the inventors of the RCA synthesizer, Harry F. Olson and Herbert F. Belar, originally embarked on the experimental development of a machine to compose songs. Using statistical analysis as the basis of their approach, the two analyzed the melodies of Stephen Foster songs with the intent of creating a machine that could synthesize new songs based on such parameters. The machine they built and tested as early as 1950 was a rudimentary form of analog computer dedicated to the input of data for the creation of songs.[1] The **Olson–Belar "electronic music composing machine"** was distinguished from other early large-scale computers because it could produce audio output from pre-programmed routines, perhaps its most significant achievement when viewed in retrospect. It was also dedicated to one task—that of composing music—unlike a general-purpose computer.

The Olson–Belar composing machine was based on information theory and developed as an aid to the composer. The machine created music based on the random selection of notes that were weighted by "a probability based upon preceding events."[2] Analysis of 11 Stephen Foster songs was carried out to determine the relative frequency of notes, patterns of note repetition, and rhythms of the songs, producing tables used to regulate the computing functions of the machine.[3] The "preceding events" were patterns of two and three notes that the engineers entered into a table to regulate the probability factors associated with selecting the next note. The frequency count of notes found in such Foster chestnuts as *Old Folks at Home*, *Oh Susannah*, *My Old Kentucky Home*, and other songs were all transposed to the key of D major for the purpose of engineering new songs with a manageable number of 12 notes. Minimizing the complexity of the note choices was important because the selection and synthesizing of pitches was all done mechanically using hardwired rotary stepper switches and relays. Table 6.1 shows the results of the initial frequency analysis of the songs.

Further analysis was conducted to determine the likelihood of one note following another in a Foster melody, the result being additional tables representing two-note and three-note sequences. Table 6.2 shows the values for the two-note sequences determined by the engineers.

In this analysis, probability was divided into sixteenths. The number 16 was chosen because it matched the number of mechanical relay channels in the output of the machine. In Table 6.2 for two-note sequences, the first two-note sequence tabulated was B_3 and there were 16 chances in 16 (100 percent certainty) that the note D_4 would follow B_3. In the third line of the table, for note D_4, there was one chance in 16 that the note B_3 would follow D_4, two chances in 16 that note D_4 would follow D_4, and so on. Regulating the selection of notes and rhythms were two random number generators. The values tabulated for the probability of notes were translated into pitch choices and the likelihood of their occurrence following any other note. A rotary stepper switch with 50 positions—one for each possible two- or three-note sequence tabulated by the

Table 6.1 Relative frequency of the notes in 11 Stephen Foster songs (after Olson)

Note	B_3	$C^\#_4$	D_4	E_4	$F^\#_4$	G_4	$G^\#_4$	A_4	B_4	$C^\#_5$	D_5	E_5
Relative frequency	17	18	58	26	38	23	17	67	42	29	30	17

Source: After Olson and Belar (1950).

Table 6.2 **Probability of the notes following a two-note sequence in 11 Stephen Foster songs***

Note	B_3	$C^{\#}_4$	D_4	E_4	$F^{\#}_4$	G_4	$G^{\#}_4$	A_4	B_4	$C^{\#}_5$	D_5	E_5
B_3			16									
$C^{\#}_4$			16									
D_4	1	1	2	5	3	1		1		1	1	
E_4		1	6	3	4			1			1	
$F^{\#}_4$			2	4	5	2		2	1			
G_4					4	3		6	3			
$G^{\#}_4$								16				
A_4			1		5	1	1	4	3		1	
B_4			1		1	1		9	2		2	
$C^{\#}_5$									8		8	
D_5								4	7	3	1	1
E_5								6		10		

Note: *The probability of the note following the preceding note is expressed in sixteenths.

Source: After Olson and Belar (1950).

engineers—responded to the output of the random number generators for rhythm and pitch and hardwired probability circuits to send an electrical signal to the tone-synthesizing component. The output could be recorded onto magnetic tape or monitored by loudspeaker. Tones were created using vibrating tuning forks amplified by contact pickups. A schematic for the Olson–Belar music composing machine is found in Figure 6.1.

However grand the intention, the aesthetic range of the resulting music was limited to the tonal structures and rhythms associated with 11 songs by Stephen Foster. Any wider application of the machine to the creation of more complex music was deemed impractical so the composing machine was essentially dead on arrival as far as the practiced composer was concerned. Olson would later write that "the creative process of the composer is not fully understood because the ability to create is a gift."[4] There is no doubt, however, that this early work of Olson and Belar did much to advance their understanding of electronic music composition and led directly to the invention of the **RCA Electronic Music Synthesizer**.

In engineering the RCA synthesizer, Olson and Belar shifted their attention from developing automated composing schema to more fully exploring the sound-generating and modification characteristics of the synthesizer. Their stated purpose was to provide a means for pre-programming all of the basic properties of musical tone, including pitch, amplitude, envelope, timbre, vibrato, **portamento**, and modifications such as frequency filtering and reverberation. Unlike the composing machine, the RCA synthesizer did not compose music but was managed by a composer who pre-programmed the machine's operation using a punched paper input device.

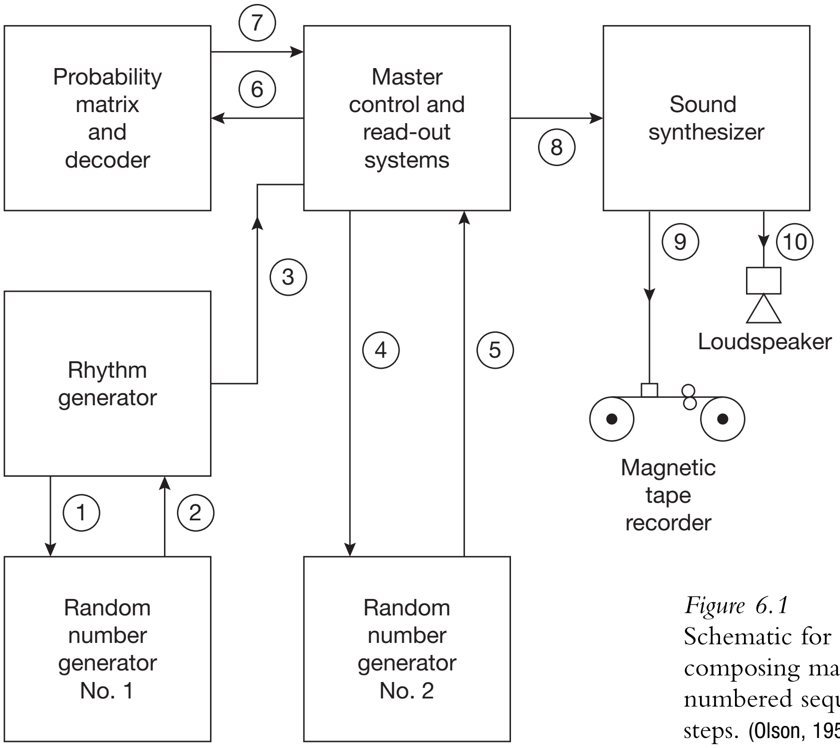


Figure 6.1
Schematic for the Olson–Belar composing machine with a numbered sequence of operational steps. (Olson, 1952)

The first RCA Electronic Music Synthesizer, also known as the Mark I, was unveiled in 1955 and housed at Princeton University where the technical staff sought the assistance of composers from the music departments of Princeton and Columbia universities. The synthesizer was designed to produce two channels of output that could be played on loudspeakers or recorded directly onto disc using a turntable lathe. Sound was generated using a bank of tuning fork oscillators amplified with pickups to produce **sine waves**—a technology borrowed from the Olson–Belar music composition machine.

In 1958, RCA created an improved version of the synthesizer called the Mark II, adding two more channels, a second punched paper input device, additional audio oscillators, and several additional means for modifying sound, including high- and low-pass filters. The original 12 tuning fork oscillators of the Mark I were supplemented by a noise generator as well as two banks of vacuum tube oscillators that could be variably tuned to nearly any pitch within the range of normal human hearing, from about 8,000 to 16,000 Hz. The expanded tone-generating capabilities of the Mark II were impressive and covered a ten-octave range. The tuning fork oscillators provided a master octave comprised of sine waves. The new electronic oscillators could produce **sawtooth** and **triangular** waves and a noise generator was also available for producing **white noise** and other audio signals with a randomized arrangement of harmonics. A **frequency shifter**, or octaver, was available as a secondary step in the synthesis of basic tones. This device was controlled by the paper tape reader. The device took a designated sine wave frequency and through a hardwired process of frequency division and multiplication added harmonics to produce a sawtooth wave composed of all even and odd harmonics. Other available modifications to the electronic source signal included the modulation of vibrato and tremolo, and a "portamento glider" that created a sliding transition from one frequency to another. A timbre modifier allowed the composer a limited amount of control over the accentuation of individual components of the overtone structure of a sound. The **envelope** characteristics of a sound could be applied to the **attack**, **duration**, and **decay** characteristics of a sound. Finally, artificial reverberation could be added to the synthesized sound and the system included a way of mixing signals for the desired balance of audio components prior to recording on magnetic tape.

The Mark II was rented for a nominal fee to Columbia and Princeton Universities and installed on the Columbia campus with the founding of the Columbia–Princeton Electronic Music Center. The Mark II is the RCA synthesizer most closely associated with the output of the studio and was actively used throughout the 1960s, eventually being superseded by voltage-controlled analog synthesizers and computer music systems. A schematic of one stage in the development of the Mark II is shown in Figure 6.2 and a diagram of the components of the synthesizer in Figure 6.3.

Of importance to the composer was the way in which sounds were specified using the RCA Electronic Music Synthesizer. The machine was equipped with a punched paper tape input device (shown by "coded paper record" on the accompanying schematic). Working directly at the console of the synthesizer, using a Teletype-like keyboard, the machine was programmed by punching holes directly onto a 15 inch (38 cm)-wide roll of perforated paper that ran at a speed of about 4 inches (10 cm) per second. Using this mechanism, the composer could enter binary codes controlling five elements for each of the two channels: frequency, octave, envelope, timbre, and volume. A piece was entered onto the punched paper tape one row at a time, presupposing a plan that was prescribed ahead of time using a worksheet (see Figure 6.4) for transposing musical notation to codes on the punched paper tape. All of this was done manually, requiring much patience and precision, but saved time by generating, without tape editing, some of the effects normally accomplished with a razor blade and splicing tape. The punched paper settings for each channel occupied one half of the width of the paper roll, providing 36 possible columns of settings for two channels. A diagram of a sample paper record, shown in Figure 6.5, denotes the number of possible settings per row for each element of a tone.

The paper punch recorder was also a reader. Below the paper was a relay tree of hardwired contact points for each possible position of a punched hole on a row. Above the paper was a series of metal brushes corresponding to the relay tree below. As the paper roll was set into motion, the brushes made contact with the relay tree whenever there was a punched hole in the paper. This contact closed a circuit, sending an electrical pulse along the relay tree to each of several separate, hardwired switches that would activate the designated frequency, octave, envelope, timbre, and volume. The paper roll contained 36 columns of possible instructions per row, 18 for each of the two channels. Olson and Belar intended the punched paper reader to allow a composer to transcribe an entire composition to a machine-readable record. The result was a permanent program or document of a piece of music that could be run through the synthesizer for playback, modification, and recording of the sounds. Even when operated at its slowest speed, however, a single, continuous roll of punched paper could only reproduce four minutes of music at the most, necessitating the construction of longer works as a sequence of smaller parts that would be joined using the facilities of the associated tape recording machines.

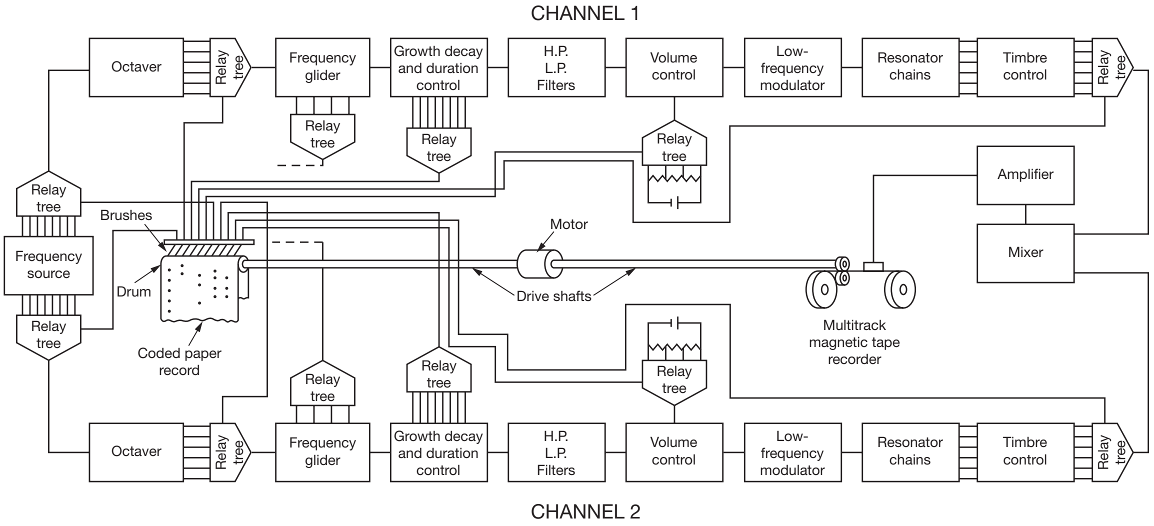


Figure 6.2 Schematic for the Olson–Belar RCA Mark II Electronic Music Synthesizer. (Olson, 1967)

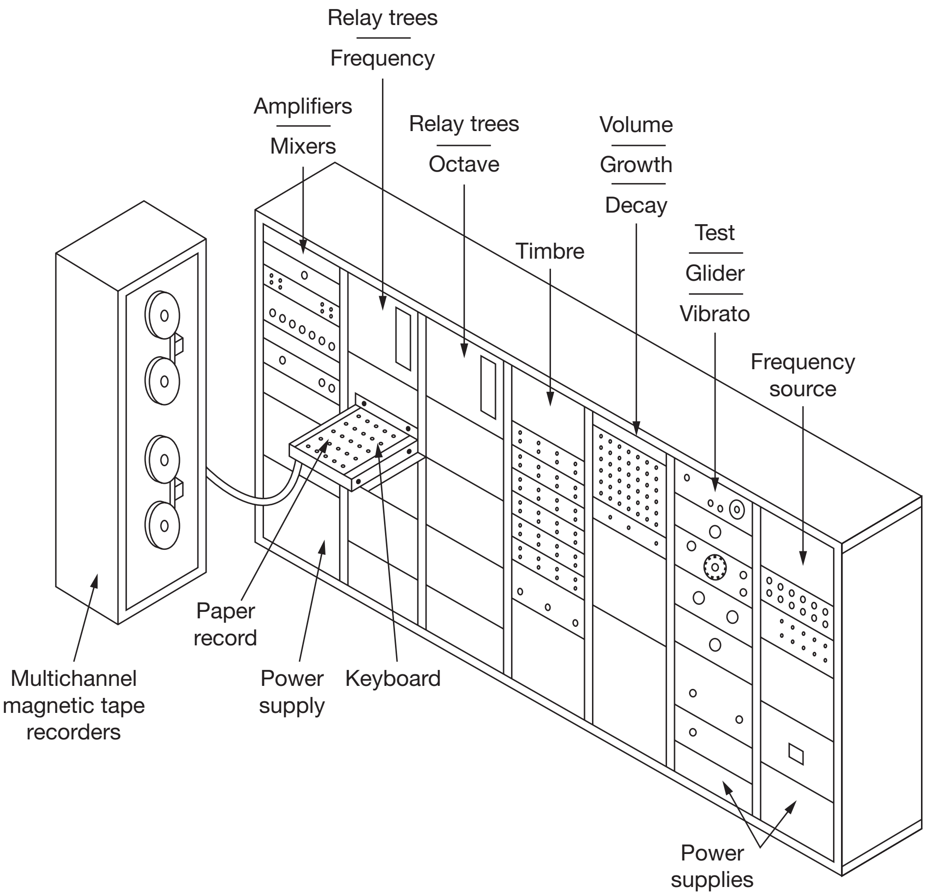


Figure 6.3 Diagram showing the operational components of the RCA Mark II Electronic Music Synthesizer. (Olson, 1967)

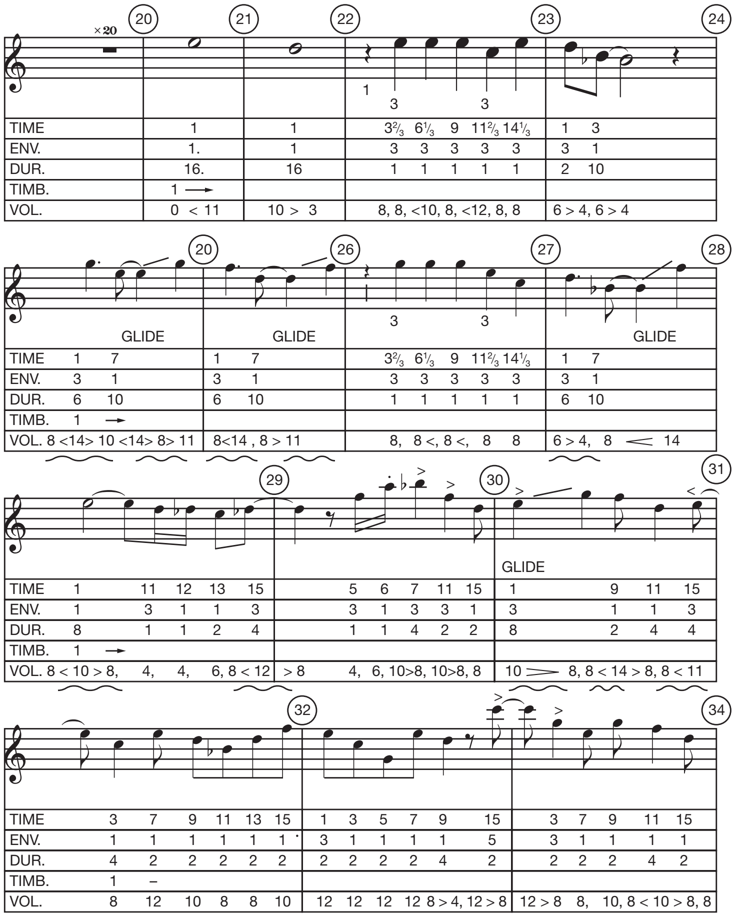
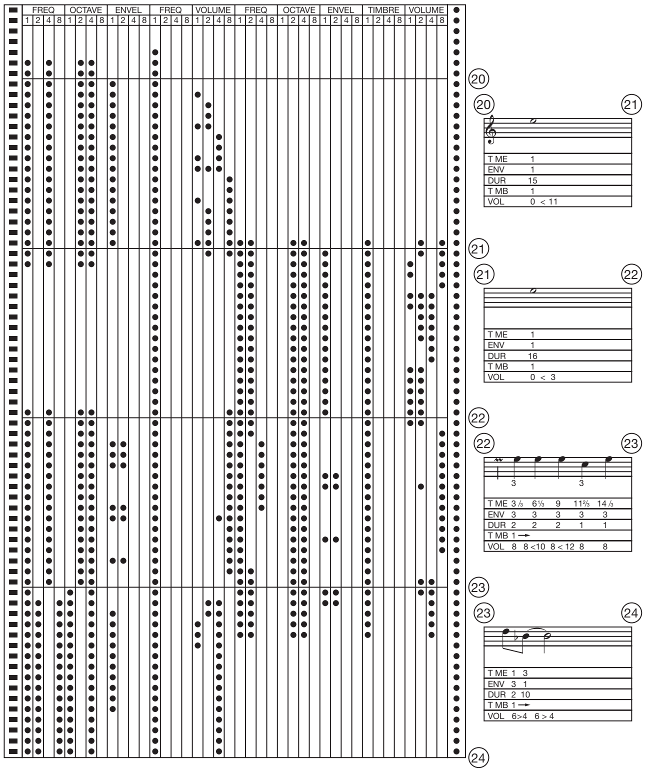


Figure 6.4 Composers using the RCA Mark II employed a worksheet to transcribe a musical score to codes for the punched paper tape input device of the synthesizer. (Olson, 1967)

While it was possible to construct a piece of music by merely recording, in real time, the output of the punched paper reader, this was not generally the approach taken at the studio. In practice, composers generally used the RCA synthesizer to create individual layers and sections of a work, often produced out of sequence, for later modification and assembly using the extensive modulation, mixing, and tape recording facilities of the studio. The sound palette for a work was also not limited to the output of the synthesizer's tone generators. Natural sounds could be input, modified, and recorded using a microphone in the studio and pre-recorded tapes of other sounds could be modified and added through the studio's tape recording facilities.

The original Mark I RCA Music Synthesizer was not equipped with a tape recorder but rather an elaborate disc-cutting lathe and playback turntable for recording purposes. Using that system, the composer could record any audio output on a disc and then combine it with other sequences being played in real time onto a new disc. Working with disc recording limited the composers to short passages of sound recording and introduced a level of mechanical dexterity and timing that made it difficult for anyone to capture and manipulate sound output. Working closely with RCA, Milton Babbitt succeeded in having the disc lathe replaced with a multitrack tape recording system in 1959.

Figure 6.5
Diagram showing the layout of the punched paper tape used to program the RCA Mark II.
(Olson, 1967)



Multitracking became a useful technique for composers who wanted to write music for more voices than the synthesizer was capable of accommodating in a single pass of the punched paper reader. Each channel of the tape recorder could record up to seven individual tone sequences, providing up to 49 tone sequences per tape through a process of overdubbing and synchronization of the paper reader for each pass. The process could be repeated again for a tape containing 49 tone sequences, multiplying the total number of available simultaneous note sequences to as many as 343 (49 × 7 tracks).

The combination of punched paper reader and multitrack recording made the RCA synthesizer ideally suited to Babbitt's 12-tone experiments. Babbitt, the son of a mathematician and advocate of serial composition, found in the RCA synthesizer the perfect laboratory with which to experiment with the total serialization of all aspects of a piece—the pitch, amplitude, envelope, timbre, rhythm, and pitch relationships in time. Babbitt completed several extended 12-tone works with the RCA synthesizer, including *Ensembles for Synthesizer* (1961–63), *Philomel* (1963–64) for soprano, recorded soprano, and synthesized accompaniment, and *Composition for Synthesizer* (1964). Such a purist was Babbitt that most of these works were completed using only those audio-generating parameters found on the punched paper score, purposefully avoiding "any further mutations or modifications" that could have been made using the extended audio processing modules of the synthesizer.[5] The resulting music was complex and arithmetic, and was comprised of complicated intersections of tone sequences, sparsely orchestrated harmonies, and carefully predetermined spasms of rhythms. Because Babbitt did not modify the sounds with reverberation, vibrato, or tape editing tricks, his works were an exercise in

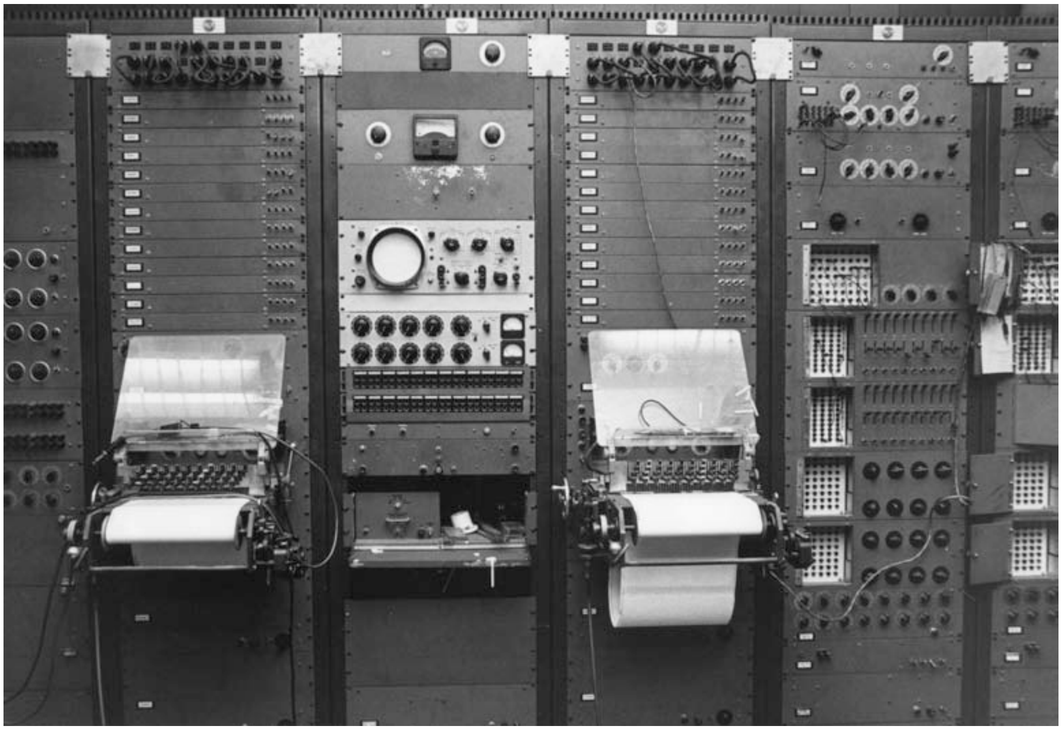


Plate 6.2 RCA Mark II front panel showing two punched paper recorder/readers. (Columbia University Computer Music Center)

Plate 6.3 Punched paper recorder/reader of the RCA Mark II. (Photo by Thom Holmes)

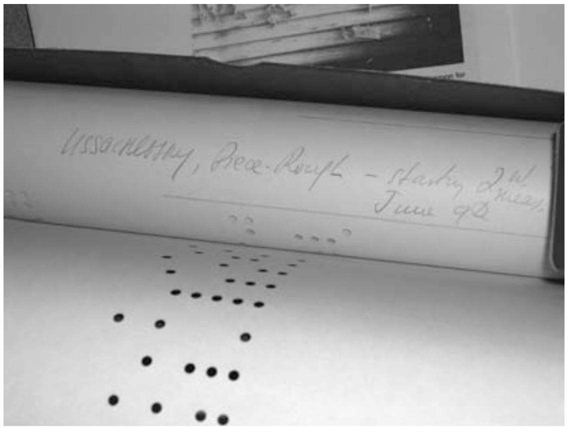


Plate 6.4 Sample punched paper roll created by Vladimir Ussachevsky and marked "Piece-Rough," *c.*1960. (Photo by Thom Holmes)

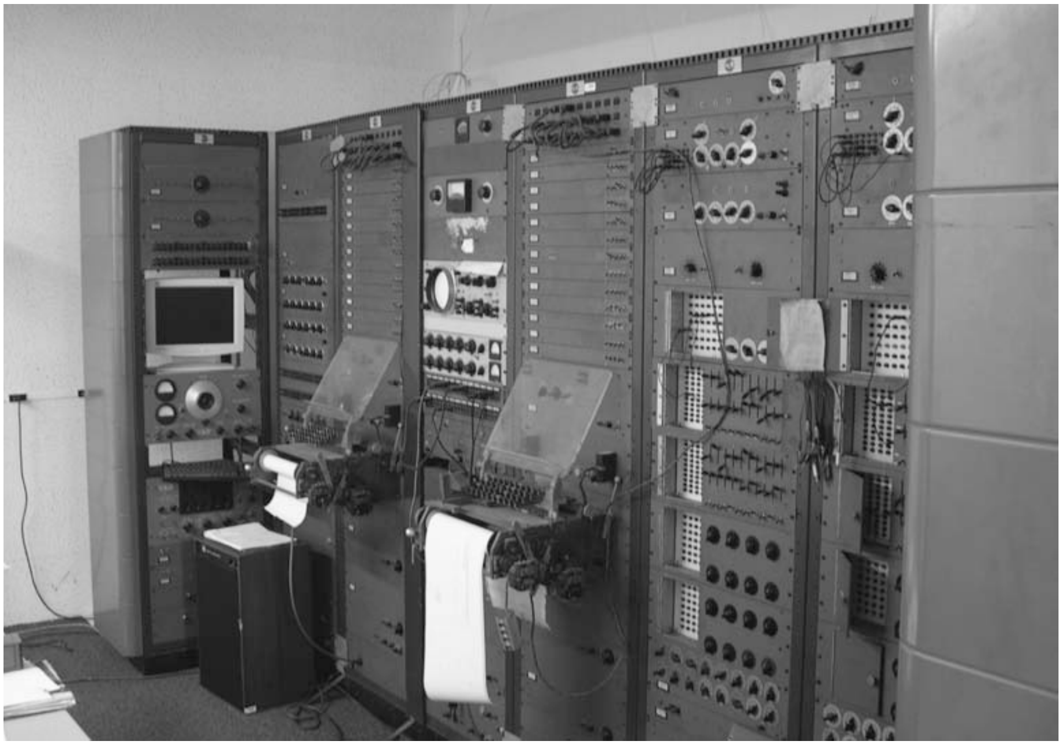


Plate 6.5 The RCA Mark II Electronic Music Synthesizer today at Columbia University. It rests in the same location in which it was originally installed in 1958. Although not currently operational, there are plans to restore the instrument. (Photo by Thom Holmes)

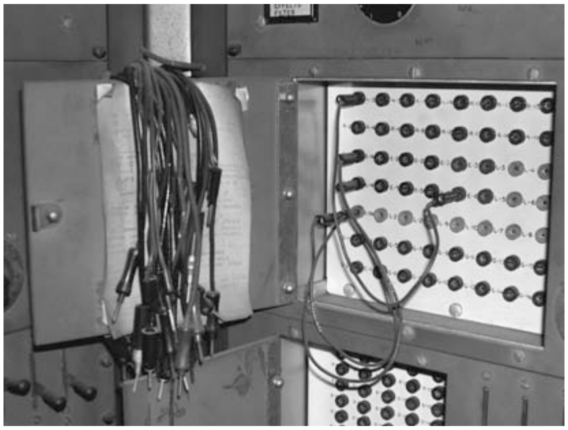


Plate 6.6 Close-up of the front panel of the RCA Mark II as it is today at Columbia University. (Photo by Thom Holmes)

Plate 6.7 Close-up of the rear panel housing circuits and vacuum tubes for one of the "resonator" modules of the RCA Mark II. (Photo by Thom Holmes)

purely abstract tones, a purpose for which the RCA synthesizer was ideally suited. In contrast to Stockhausen, whose early serial compositions for sine waves were always colored psychologically by carefully metered tape effects, reverberation, and speed shifts, Babbitt's works were stripped of such emotional content as anticipation, resolve, and acoustically familiar reverberations, resulting in a listening experience that was fascinating because of its austere complexity as well as its disassociation from human experience.

The RCA Mark II Electronic Music Synthesizer weighed about 3 tons, stood 7 feet tall, was 20 feet long, contained 1,700 vacuum tubes, and was the centerpiece of the studio in which it was housed. To the untrained eye the machine most closely resembled a mainframe computer. This was not surprising, because its electronics consisted of vacuum tube components and hardwired circuits used for the first, analog, general-purpose computers. The studio and its equipment continued to evolve. During the early 1960s, the punched paper reader was replaced with a somewhat more flexible optical recognition system that responded to ink marks on paper rather than hole punches. With the availability of commercial analog synthesizers by 1965, the RCA synthesizer was supplemented with the modular, solid-state Buchla synthesizer, Ampex tape recorders, and expansion of the studio's workspace to include several individual workstations for composers. By 1969, the RCA synthesizer was much less used and was all but supplanted by four similarly equipped studios featuring Buchla synthesizers, individual wave generators, four-track and two-track tape recorders, and a central mixing console. The mixing console connected all of the studios, allowing up to 24 individual inputs from the satellite studios.[6] Milton Babbitt was probably the last serious advocate of the RCA synthesizer and reportedly still favored it for his electronic works as late as 1972.[7]

Another electronic piece composed later in the life of the RCA synthesizer was *Time's Encomium* (1968–69) by Charles Wuorinen (b. 1938). This work also has the distinction of being the first electronic work to win the Pulitzer Prize for music. Wuorinen's stated goal was to explore the "precise temporal control" such as note-to-note distances and absolute time values that could be assigned by the synthesizer, mapping a sequence of pitch and time relationships.[8] Like Babbitt, Wuorinen chose only the purest, most unadulterated tones of the RCA synthesizer for the first 15 minutes of the work. For the second half, he reworked the recorded tone patterns from the first half using the sound processing and tape facilities of the studio.

As a technological marvel, the Olson–Belar RCA Electronic Music Synthesizer was well suited for the composition of 12-tone music but its elaborate punched paper input system was of little value to most composers working in the Columbia–Princeton Electronic Music Center. Alice Shields (b. 1943), whose tenure at the studio began in 1963 as an assistant to Ussachevsky, was one such composer:

> No one, to my knowledge, composed a piece on the RCA (which arrived at the studio around 1959), but Milton Babbitt and Charles Wuorinen. I had little interest in it, as the timbres were very limited, and the key-punch mechanism was so inferior to music notation for live instruments whose timbres were not at all limited. My interest was, and largely still is, in "concrete" or sampled sounds as sources for electronic manipulation and transformation.[9]

The output of the Columbia–Princeton Electronic Music Center varied considerably with the taste and inclination of each visiting composer. Internationally known composers were often invited to use the center. In the first two years, it sponsored work by such composers as Michiko Toyama (b. 1913) from Japan, Mario Davidovsky (b. 1934) from Argentina, Halim El-Dabh (b. 1921) from Egypt, Bulent Arel (1919–90) from Turkey, and Charles Wuorinen from the United States. The center drew on this body of work when it presented its first public concerts on May 10, 1961, in the McMillan Theater of Columbia University. The program consisted of seven works, six of which were later released on a Columbia record album. These works were tape pieces alone or involved the interaction of live musicians with tapes of synthesized sounds. Aside from the use of the RCA synthesizer and the center for 12-tone composition, many prominent and up-and-coming composers contributed to the studio's growing repertoire of adventurous works using a wide variety of compositional approaches. Varèse himself used the studio in 1960 and 1961 to revise the tape parts to *Déserts* with the assistance of Max Mathews and Bulent Arel.[10] Hundreds of composers passed through the center to take a closer look and often work in the studio. Babbitt remarked that the center was instrumental in helping people to better understand what electronic music was about and to "disabuse them of the notion that it's a particular kind of music." Babbitt recalled that Stravinsky "had a heart attack there, he got so excited."[11] In addition to Ussachevsky, Babbitt, Luening, Varèse, Arel, and Mathews, other noted composers who used the center included Tzvi Avni (b. 1927), Luciano Berio, Wendy Carlos, Mario Davidovsky, Charles Dodge (b. 1942), Jacob Druckman (1928–96), Halim El-Dabh, Ross Lee Finney (1906–97), Malcolm Goldstein (b. 1936), Andres Lewin-Richter (b. 1937), Ilhan Mimaroglu (b. 1926), Jon Appleton (b. 1939), Pauline Oliveros, Alwin Nikolais (1910–93), Mel Powell (1923–98), William Overton Smith (b. 1926), and Charles Wuorinen. More electronic music was released on record from this single studio than from any other in North America.

Wendy Carlos, a graduate student at Columbia at the time, ran tape machines for the premiere of Babbitt's *Philomel* in 1964.[12] Carlos's own *Variations for Flute and Electronic Sound* (1964) was written for a flutist accompanied by magnetic tape. The work consisted of a "strictly organized set of six variations on an eleven bar theme stated at the outset by the flute."[13] Mimaroglu's *Le Tombeau d'Edgar Poe* (1964) used as its only sound source a recorded reading of the Mallarmé poem, utilizing the full spectrum of studio editing techniques and effects to modify and transform the sound. Davidovsky's *Electronic Study No. 1* (1960) used the purely electronic sound sources of sine waves, square waves, and white noise modified through the use of filters and reverberation, then layered five times, inverted, and transposed to change their amplitude and density. *Animus I* (1966) by Jacob Druckman employed a live trombonist who traded passages with a tape of electronic sounds, eventually being driven off the stage by the ensuing pandemonium; it concluded with the musician returning for an uneasy truce with the tape recorder.

One of the most influential composers associated with the early years of the studio was Halim El-Dabh, who worked there from 1959 to 1961 (see Innovation box, p. 156). Although El-Dabh soon moved on from the studio to begin a long and distinguished career as an ethnomusicologist and composer, his early tape piece *Leiyla and the Poet* (1961) became something of a cult favorite with up-and-coming composers who heard it on a recording released in 1964.[14] El-Dabh's seamless blending of vocal sounds, electronic tones, and tape manipulation such as speed transposition gave the short work—part of a longer multipart electronic opera—an unearthly quality that influenced many young composers working at the time. His approach to composing electronic music was one of immersion in the sound. While at Columbia, he made full use of all ten Ampex tape recorders available to him, often working throughout the night and sleeping on Ussachevsky's cot in a back room at the studio. "I always like the idea of solid noise, and I felt like a sculptor who was chiseling the sound away," revealed El-Dabh. Some of his material consisted of loops that were so long that they had to be run out of the room and back.[15] The roster of people who acknowledge the importance of El-Dabh's recording to their work ranges widely from Neil Rolnick to Charles Amirkhanian, Alice Shields, and rock musician Frank Zappa.[16] *Leiyla and the Poet* had a certain degree of crossover appeal to other genres of music and was the obvious and imitated source of the song *Leiyla* (1967) by the Los Angeles-based rock band The West Coast Pop Art Experimental Band, two members of which were the sons of composer Roy Harris.

The Columbia–Princeton Electronic Music Center and the Olson–Belar RCA synthesizer were groundbreaking in many respects. The synthesizer, although bearing tone-generating capabilities limited to the 12-tone scale, radically modernized the degree of control given the composer over the synthesized result. The punched paper recorder/reader was a precursor of machine-controlled input devices that would become available on large-scale computer music systems during the 1960s and provided unprecedented control over the basic audio parameters of musical sounds. The modular design of the audio signal processing components of the RCA synthesizer would be duplicated more efficiently in commercially available voltage-controlled synthesizers of Buchla and Moog in the mid-1960s. The multitrack tape recorder anticipated the widespread availability of overdubbing in commercial recording studios.

It would be unfair to assign total credit for the success of the Columbia–Princeton Electronic Music Center to the technological feats of programmability, modularity, and mixing/recording capabilities of the RCA synthesizer. This was a studio with a list of completed works that rivaled in number those produced in the public broadcasting facilities of Paris and Cologne radio; a reported 225 works were produced at the Columbia–Princeton studio in its first decade of operation.[17] The majority were produced using ancillary audio processing equipment at the center rather than the RCA synthesizer and most works could be described as using concrete or electroacoustic sources rather than the 12-tone system embodied by the synthesizer proper. Shields elaborated on the RCA synthesizer and the body of works created at the studio:

> The machine was always very delicate, with its punch keys and little telephone cables, and looked somewhat decayed and disheveled even when I arrived in 1963 at the Center. One of the reasons it was so little used was indeed its delicacy, and that I believe in Vladimir's mind it had to be preserved in as intact a state as possible for the use of Milton Babbitt . . . Still another reason it wasn't attractive to most composers was that it allowed only the tempered scale, and in the 1960s all the conflagration of wild experimentation and newness was in almost anything but the tempered scale. The RCA was obviously designed by engineers, not composers. But it was always interesting to visiting groups who I would take around the Center and demonstrate various pieces of equipment and play compositions made at the Center. When I brought them in front of the RCA, they would always take a deep breath of satisfaction, impressed, when they saw the huge metal box with its key-punches and telephone wires . . . But it was at

Plate 6.8
Alice Shields at the Columbia–Princeton Electronic Music Center, 1970. (Alice Shields)

> the least a good visual advertisement for the Center, in addition to providing Milton with a device well suited to his compositional concerns.[18]

Babbitt also found the RCA synthesizer to be unreliable:

> It was not a comfortable device . . . You never knew when you walked in that studio whether you were going to get a minute of music, no music, two seconds of music. You just didn't know what you were going to get. You never knew what was going to go wrong. You never knew what was going to blow.[19]

Behind the technical achievements of the center was a joint venture between two noted university music schools that opened the facilities to established composers and students alike. Ussachevsky, who held degrees in engineering and music, was not only an able administrator but prescribed the functional requirements for many of the ancillary audio processing devices created by Peter Mauzey, James Seawright, Virgilio de Carvalho, John Bittner, and other technicians working at the center.[20]

The Columbia–Princeton Electronic Music Center was the first notable university-based electronic music studio in North America, a trend that shifted activity in the field away from commercial studios or broadcasting establishments to educational institutions. The result was greater access to equipment and a nurturing environment in which to learn the art of electronic music. Significantly, the center became one of the first studios to provide opportunities for women and people from a wide variety of ethnic and racial backgrounds. Among the earliest practitioners in the studio were the Egyptian composer Halim El-Dabh (1959), the Japanese woman composer Michiko Toyama (1959), and American women Alice Shields and Pril Smiley (from about 1963 to the mid-1990s), Pauline Oliveros (1966), and Ann MacMillan (from the late 1960s to 1970s). Alice Shields credits Vladimir Ussachevsky with encouraging women composers to work at the studio. Shields and Pril Smiley (b. 1943) in particular had pivotal roles at the center, assisting in the technical management of the studio while also composing and teaching others in the use of the facilities. El-Dabh, Shields, and Smiley remain active in music to this day,

HALIM EL-DABH—ELECTRONIC MUSIC PIONEER

Plate 6.9 Halim El-Dabh, early 1950s. (Halim El-Dabh)

The career of Egyptian-born Halim El-Dabh (b. 1921) has spanned more than 60 years, during which he has become known as an influential composer, performer, ethnomusicologist, and educator. He arrived in the United States in 1950 after having received a Fulbright Scholarship and studied music with Ernst Krenek at the University of New Mexico and was tutored by Aaron Copland, among others, for two summers at the Berkshire Music Center. Only five years earlier, having earned a degree in agricultural engineering from Cairo University, a career in music was the farthest thing from El-Dabh's mind. Although he was earning a living as an agricultural consultant, El-Dabh was also interested in music and had been privately composing and playing piano music. It was one of his early piano works and his innovative performance technique that earned him recognition in Egypt and brought him to the United States to further his musical studies. Equally important to El-Dabh's early career were his early experiments with electronic music.

El-Dabh composed one of the earliest known works of *musique concrète* in 1944, four years before Pierre Schaeffer would become famous for having coined that term to describe his experiments with recorded sound in Paris. While studying in Cairo, El-Dabh gained access to a magnetic wire sound recorder through the offices of Middle East Radio. He was allowed to borrow the wire recorder and, although it weighed 17 pounds and required a heavy microphone and power cable, El-Dabh took it into the streets to capture outside sounds. The primary subject of his recordings was a "pre-Islamic ritual" called a *zaar* ceremony, consisting of African-influenced vocal music and dances.[21] El-Dabh was fascinated by the possibilities of manipulating recorded sound for musical purposes but he had no models to go by. It seemed to him that the recording equipment from the radio station could open up the raw audio content of the *zaar* ceremony to further investigation, to unlock "the inner sound" that was contained within. "I just started playing around with the equipment at the station," explained El-Dabh, "including reverberation, echo chambers, voltage controls, and a re-recording room that had movable walls to create different kinds and amounts of reverb."[22]

Using the equipment at his disposal, El-Dabh deconstructed the sound of the women's voices, concentrating in particular on the rhythm of the singing and overtones in the upper registers:

> I concentrated on those high tones that reverberated and had different beats and clashes, and started eliminating the fundamental tones, isolating the high overtones so that in the finished recording, the voices are not really recognizable any more, only the high overtones, with their beats and clashes, may be heard.[23]

Working in this way, isolated from the mainstream of contemporary music at the time, El-Dabh independently discovered the potential of sound recordings as the raw material from which to compose music. The final piece was transferred to magnetic tape and lasted between 20 and 25 minutes. El-Dabh called the work *The Expression of Zaar* (1944) and it was first presented publicly during an art gallery event in Cairo.

By the time that Otto Luening and Vladamir Ussachevsky became acquainted with El-Dabh's music in 1955, the Egyptian composer had been dabbling in electronic music for more than ten years. When the Columbia–Princeton Electronic Music Center was established in 1959, El-Dabh was among the first outside composers invited to work there. His approach to combining spoken word, singing, and percussion sounds with electronic signals and processing added significantly to the development of early electroacoustic techniques produced at the center. El-Dabh completed eight works at the center in 1959, including a multipart electronic opera, *Leiyla and the Poet* (1959), an excerpt of which was released on a collection of works from the center by Columbia Records.[24]

El-Dabh's musical style was unlike the mathematically derived compositions of Babbitt and other serial composers working at the center. His interest in ethnomusicology and the fluid blending of native folk music elements with electronic sounds made his works starkly original. His early electronic works remain as fresh today as they did 50 years ago. "The creative process comes from interacting with the material," El-Dabh explained. "When you are open to ideas and thoughts the music will come to you."[25]

El-Dabh became a US citizen in 1961 and has held professorships at several universities including posts in music and pan-African studies at Kent State University. He retired from Kent State in 1991, but continues in the role of visiting professor. A recently released CD of his works brought together for the first time his most important electronic music from the Columbia–Princeton Electronic Music Center as well as his early wire recording piece from 1944.[26]

having had the opportunity to explore the outer reaches of music as part of their early experiences at the Columbia–Princeton Electronic Music Center.

The Columbia–Princeton Electronic Music Center is still in operation although the RCA synthesizer is no longer operable and has been relegated to the status of a museum display. Before Shields left the center in 1996, she brought back fellow alumni Wendy Carlos to help label and archive the vast store of handmade electronic processors, mixing boards, tape recorders, and other valued gear that was no longer in active use.

The Siemens Studio für Elektronische Musik

In 1955, about the same time that Olson and Belar were unveiling the RCA Mark I Electronic Music Synthesizer in the United States, German electronics manufacturer Siemens established an audio laboratory in its Munich facilities to produce electronic music for its promotional films. Siemens engineers Helmut Klein, Alexander Schaaf, and Hans Joachim Neumann were charged with assembling the components for the studio and providing a means for controlling the composition, synthesis, and recording of music (see Figure 6.6). The team was well acquainted with the application of electronic technology for telecommunications applications. Klein had previously worked on the

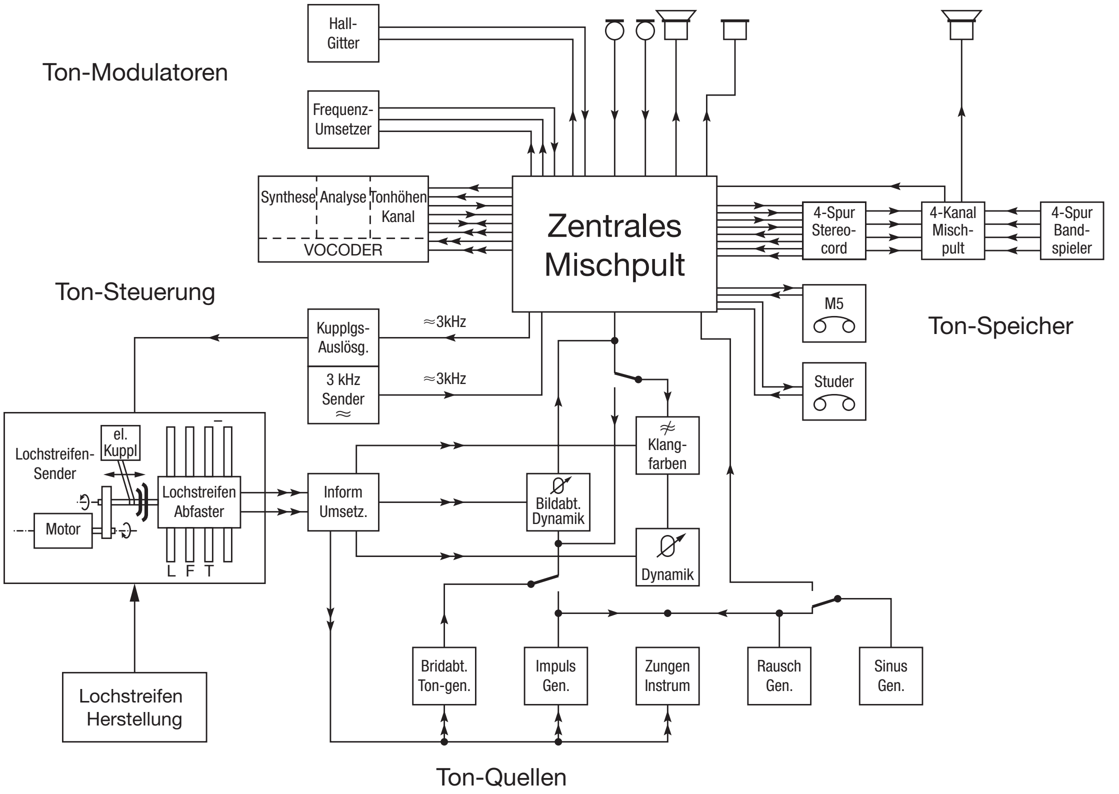


Figure 6.6
Schematic of the Siemens Studio für Elektronische Musik, 1960. (Siemens)

development of the Siemens **vocoder** (voice encoder–decoder)—a voice synthesis system used to mimic the human voice based on earlier patents at Bell Labs. Schaaf had the design of a loudspeaker system to his credit and Neumann was a recent university graduate with experience in the analysis of sound spectra.[27] The group then contracted composer Josef Anton Riedl (b. 1929) to serve as artistic director and conductor of music projects because of his familiarity with the development of music for films.

Under the guidance of Riedl, the laboratory took shape so that by 1956 the engineering staff was making progress in integrating an assemblage of otherwise individual components, not all of which were originally intended for music production. Equipment found in the **Siemens Studio für Elektronische Musik** (Siemens Studio for Electronic Music) included a vocoder, an electrically amplified reed instrument known as the Hohnerola, a preset sawtooth wave generator with 84 tone gradations, four variable-controlled sine wave generators, 20 special purpose sine wave generators, each with fixed settings of 15–160 Hz, 150–1,600 Hz and 1,500–16,000 Hz, that could also be switched to sawtooth waveforms, and a white noise generator. Audio processing of the output signals could employ reverb, echo, and a method for shifting the frequencies to different ranges. The vocoder was an especially effective device for applying tonal qualities of the human voice to any input signal. It consisted of 20 stacked band-pass filter channels, each tuned to a different frequency range with a bandwidth of 6,000 Hz. The vocoder could be likened to a smart, analog equalizer that measured the fundamental frequency of the incoming signal and then reproduced as nearly equivalent signals on the output for each channel.

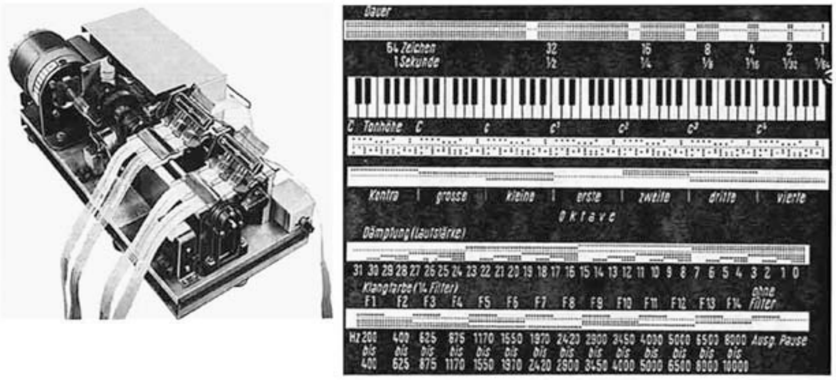


Plate 6.10
Four paper tape input devices were used in the Siemens studio to control the pitch, volume, duration, and filtering characteristics of electronic sounds. (Siemens)

Riedl was also interested in adding some level of control over the programming of tones, not unlike what he had learned about the punched paper recorder of the RCA synthesizer. For this purpose, the German engineers employed four telex-like punched paper tape recorders to store and play back binary commands controlling the pitch (up to 7 octaves using a 12-tone scale), volume (set in 32-step increments of 1.5 dB each), timbre (applying band-pass filters), and duration (for reproducing whole, quarter, eighth, and sixteenth notes). The method of coding the paper tape was more user-friendly than the RCA punched paper reader and allowed the composer to play a note on a piano-style keyboard before recording it as a hole on the paper tape. The volume and timbre of each note was determined using rotary dials. In 1960, the system was outfitted with a supplemental input device in the form of the *Bildabtaster* (image sensor)—an optical reader capable of converting graphic images into tones and volume settings—a gadget that inspired the creation of electronic music from freehand drawings and paintings.

The organization of the Siemens Studio für Elektronische Musik was completed by 1959, and included tape editing stations and a master mixing console. Between 1960 and 1966, the studio opened its doors to many outside composers and produce widely diverse output. Riedl worked continuously in the studio during this period and produced no fewer than 44 works, many for motion pictures and industrial films.

The studio achieved the status of a state-of-the-art studio in Europe much like the Columbia–Princeton Electronic Music Center had in the United States. It became the stopping-off point for many prominent visitors, including Pierre Boulez, Herbert Brün, Ernst Krenek, Karlheinz Stockhausen, Bruno Maderna, Henri Pousseur, Mauricio Kagel, Werner Meyer-Eppler, Abraham Moles, and many others, although only a few of these people—including Kagel, Pousseur, Brün,

Plate 6.11 The Siemens Studio für Elektronische Musik, 1960. (Siemens)

and Krenek—completed important electronic works there. The studio was closed in 1967 but its main control room and equipment have been preserved as part of a museum exhibit at the Siemens Museum in Munich.

Although not designed from the ground up as an integrated synthesizer like the Olson–Belar RCA synthesizer, the Siemens Studio für Elektronische Musik offered many of the same advantages for the composer, including a method for controlling its tone-generating facilities, modification and modulation of the sounds in real time, and the manipulation of recorded material into finished works.

Early Voltage-Controlled Components

Developments at both the Columbia–Princeton Electronic Music Center and the Siemens Studio für Elektronische Musik represented a bridge from the purely electromechanical synthesizer to voltage-controlled instruments that permitted improved programmability for the composer. **Voltage control** is a method of applying metered amounts of current to an electronic component to govern how it operates. The application of control voltages can be likened to manually turning the volume knob on a stereo system: the further up or down the dial is turned governs the amount of current fed to the amplification circuitry that drives the loudspeakers.

Analog electronic music components such as oscillators, amplifiers, and filters can all be controlled by control voltages. The **voltage-controlled oscillator** (**VCO**) is a simple example. The more voltage is applied to the input of the oscillator—e.g. through a manually rotated dial, patch cord, or preset switch—the more rapidly the oscillator will vibrate and the higher the frequency of its pitch.

Designing voltage-controlled electronic music components was less practical until the affordability of transistorized, solid-state electronic music components in the 1960s. Prior to the availability of low-powered solid-state circuit boards, the use of voltage control relied on significantly higher current levels, hardwired circuits, and vacuum tubes that had a short lifetime. Even so, voltage control was used as the basis for the design of some experimental components found in electronic music studios of the 1940s and 1950s. Homer Dudley's vocoder (1939), designed to analyze and reproduce the sound of the human voice, generated control voltages to shape the envelope and amplification of the input signal it was analyzing.[28] Harald Bode, a German engineer who developed many electronic instruments and components found in the first European studios, developed a voltage-controlled amplifier in 1959 as part of a broader modular sound modification system.[29] Composer Vladimir Ussachevsky of the Columbia–Princeton Electronic Music Center and Peter Mauzey, the lead technician of the studio, also experimented with voltage-controlled devices. Mauzey was one of Moog's instructors when he studied engineering at Columbia University in the 1950s. In 1965, Ussachevsky gave Moog specifications for the construction of a voltage-controlled envelope generator. Moog recalled the significance of the idea:

> I built two voltage-controlled amplifiers, two envelope generators, and two envelope followers. Ussachevsky wrote the specifications for these modules. He wanted the envelope generators to have four parts: Attack, Decay, Sustain, and Release. He was the first one to specify the ADSR envelope. Now it is standard on electronic synthesizers and keyboards.[30]

EARLY SYNTHESIZERS AND EXPERIMENTERS

LISTEN

1. *The Expression of Zaar* (alt. title *Wire Recorder Piece*, 1944) by Halim El-Dabh
   Middle East Radio, Cairo; composed using a magnetic wire recorder
2. *Dripsody* (1955) by Hugh Le Caine
   Using Le Caine's Special Purpose Tape Recorder
3. *Folge von 4 Studien* (1959–62) by Josef Anton Riedl
   Siemens Studio für Elektronische Musik
4. *Electronic Study No. 1* (1960) by Mario Davidovsky
   Columbia–Princeton Electronic Music Center
5. *Leiyla and the Poet* (1961) by Halim El-Dabh
   Columbia–Princeton Electronic Music Center
6. *Antithese* (1962) by Mauricio Kagel
   Siemens Studio für Elektronische Musik
7. *Ensembles for Synthesizer* (1961–63) by Milton Babbitt
   Using RCA Mark II Electronic Music Synthesizer
8. *Space Mystery* (1963) by Raymond Scott
   Using Scott's Electronium
9. *I of IV* (1966) by Pauline Oliveros
   Produced at the University of Toronto Electronic Music Studio using Hugh Le Caine's tape loop system
10. *Time's Encomium* (1968–69) by Charles Wuorinen
    Using RCA Mark II Electronic Music Synthesizer

The subject of voltage control and analog synthesis is more completely explored in Chapter 7.

Raymond Scott

Raymond Scott was a commercial musician and inventor of electronic musical instruments whose work largely went unnoticed because he worked privately rather than as part of an institution.[31] Yet anyone who grew up in the 1950s or 1960s heard his electronic music at one time or another. Scott was the composer and electronic architect of a myriad of jingles, special effects, mood pieces, and other commercial applications of electronic music for radio, television, and industrial films. His specialty was the snappy tune, space-age sounds, and joyful electronic abstractions—all for hire. His work was used for a diverse portfolio of organizations and products ranging from Nescafé coffee to spark plugs, Bufferin pain reliever, General Motors, IBM, Hostess Twinkies, and Baltimore Gas and Electric, to name a few.

Prior to his endeavors as a designer of "plastic sounds" and "audio logos" for commercial purposes, Scott was most visible as a bandleader. Many of his catchy melodies—*Powerhouse*, *Twilight in Turkey*, *Dinner Music for a Pack of Hungry Cannibals*—were adapted for use in cartoons by legendary Warner Brothers music director Carl Stalling (1888–1974) during the 1940s and 1950s.

The other side of this man was little known to the public. Scott was at heart a self-taught electronics wizard and spent many of his early years soldering, tinkering, and inventing musically oriented contraptions. By the late 1940s, he had accumulated enough wealth from his work as a bandleader and composer to purchase a large home in North Hills, Long Island. In it were eight rooms devoted to his electronic experiments. He had a professionally outfitted machine shop for making electronic equipment and a spacious recording studio with a disc lathe, reel-to-reel tape recorders, and a wide assortment of wall-mounted instruments, mixers, and controls that grew more complex from year to year as he continued to invent new audio processing devices and musical instruments.[32]

Scott occasionally reached out to other engineers to obtain gear. Robert Moog recalled a visit he and his father made to Scott's home around 1955. Scott was interested in using one of the younger Moog's Theremin circuits. Robert Moog later remarked:

> I can't remember the first time I saw that much stuff. But you don't go from having nothing one day to having 30 feet of equipment the next. Scott probably was fooling with that kind of stuff for years and years.[33]

Plate 6.12
Raymond Scott in his home studio, 1959.
(Raymond Scott Archives, Manhattan Research Inc.)

During the 1950s and 1960s, Scott and Eric Siday—another early customer of Robert Moog's—were the two most sought-after composers of music for radio and television commercials. Scott formed Manhattan Research Inc. as an outlet for his commercial electronic music production. By about 1960, he was offering a grab bag of gadgets for various musical applications, including four models of electronic doorbells, an electronic music box, and three models of an instrument he called the Electronium. By the mid-1960s, Scott's printed advertising billed Manhattan Research Inc. as "Designers and Manufacturers of Electronic Music and Musique Concrète Devices and Systems."[34] His most unique inventions included a variety of keyboard instruments, multitrack recording machines, and automatic composing instruments.

Multitrack Tape Recorder (1953)

Scott invented two of the earliest multitrack magnetic tape recorders. His patented machines could record seven and fourteen tracks on a single reel of tape using multiple tape heads. Les Paul (b. 1915) had previously used the technique of recording sound-on-sound in the early 1940s, but that method only involved recording from one monophonic tape recorder to another while playing along in real time. Scott's multitrack machines recorded seven or fourteen parallel audio tracks on the same reel of tape. Paul made a prototype of an eight-track machine in 1954,[35] and in 1955 Hugh Le Caine (1914–77) invented a machine that mixed six separate but synchronized tapes down to one track.

Clavivox (1959)

This was a three-octave keyboard instrument resembling a small electronic organ. It used the beat frequency principles of the *Ondes Martenot* and Theremin but had the unique ability to slide notes from key to key at adjustable rates of portamento. The Clavivox also had left-hand controls for vibrato, hard attack, and soft attack, and a mute button that allowed the player to abruptly silence a note while it was on the rise.[36] The instrument was one of the few products that Scott marketed commercially, although relatively few were made.

Plate 6.13 Raymond Scott's Clavivox. (Photo by Thom Holmes)

Electronium (1959–72)

Scott once remarked that "the Electronium is not played, it is guided."[37] Scott's remarkable "instantaneous composition/performance machine" evolved many times over the years and grew in sophistication as he continually cannibalized components from his other equipment. The Electronium was a semi-automated composing synthesizer without a keyboard. Controlled by a series of switches on the face of the instrument, the composer could preset melodies, tempos, and timbres or recall previously prescribed settings. After making initial settings for the music, the Electronium was set into motion and made additional parameter changes on its own, automating the creation of tunes according to the basic rules initiated by the composer. Polyrhythms and multiple parts for the music were performed and recorded in real time without the aid of multitrack tape recording.[38] The Electronium also used "processes based on controlled randomness to generate rhythms, melodies, and timbres."[39] In an operator's manual for one version of the Electronium, the inventor described the composing process as follows:

> A composer "asks" the Electronium to "suggest" an idea, theme, or motive. To repeat it, but in a higher key, he pushes the appropriate button. Whatever the composer needs: faster, slower, a new rhythm design, a hold, a pause, a second theme, variation, an extension, elongation, diminution, counterpoint, a change of phrasing, an ornament, ad infinitum. It is capable of a seemingly inexhaustible palette of musical sounds and colors, rhythms, and harmonies. Whatever the composer requests, the Electronium accepts and acts out his directions. The Electronium adds to the composer's thoughts, and a duet relationship is set up.[40]

Scott designed the Electronium to produce in hours what would have normally taken days or weeks for a composer to write out as scored music. He envisioned the device as a cost-saving innovation for the production of television and motion picture music.

Scott also developed a sophisticated, electro-mechanical switching **sequencer** to control his racks of electronic music devices.[41] This predecessor of the voltage-controlled sequencers developed by Moog could produce rhythmically uniform sequences "in which 200 elements can be combined in infinite permutations of pitch, tempo, meter, timbre, or special mood."[42] Some of the components of the sequencer found their way into the design of the Electronium.

The Electronium took Scott ten years to perfect. When he offered it for sale in 1970, Motown Music Inc. immediately expressed interest in buying one. Motown hired Scott to be their technology consultant for several years. His one and only commercially produced Electronium was delivered to Motown in the early 1970s and now resides in the Hollywood-based studio of Devo member Mark Mothersbaugh, who hopes one day to restore it to operating condition.

Scott was secretive about his musical invention and feared that others would steal his trade secrets. Aside from filing for patents, Scott did little to reveal the technology of his inventions to others. He was not interested in explaining his technology to other engineers but was more than willing to give lively demonstrations at advertising and media conventions. Even those who supplied Scott with components had no idea what they would be used for. "He never bought our stuff with the idea that he would plug it in and use it," recalled Robert Moog. "He was developing his own instrumentation. During the early days of us making synthesizers, Scott wanted us to make little things that he would then incorporate into instruments he was working on."[43]As a result, Raymond Scott had minimal influence on the evolution of music technology.

Hugh Le Caine

Canadian Hugh Le Caine was a physicist who, after helping develop early radar systems during World War II, turned his attention to designing electronic music devices. Among his achievements, Le Caine invented an early voltage-controlled synthesizer nearly 20 years before similar technology became widely available through the work of Robert Moog and Donald Buchla.

Whereas Raymond Scott was reluctant to share his musical inventions with other engineers, Le Caine was a product of academia and made his work known as a matter of course. He frequently contributed to the engineering literature and by 1954 was employed full-time by Canada's National Research Center to work on his electronic music inventions. This was a privileged position seldom afforded to an engineer of music technology in any country. For 20 years, this gifted and affable inventor devised innovative audio processing and synthesizing gear and nearly "single-handedly equipped electronic music studios at the University of Toronto (opened in 1959) and at McGill University in Montreal (opened in 1964)."[44] Le Caine is acknowledged as a major influence by both electronic music composers and engineers. Robert Moog, who invented the first commercially successful voltage-controlled synthesizer in the mid-1960s, called Le Caine a "profound influence" on his work.[45] His inventions ranged from multitrack tape recording methods to electronic keyboard instruments and analog sequencers.

Electronic Sackbut (1945–73)

Le Caine began working on the Electronic Sackbut synthesizer in 1945 and continued to upgrade the instrument in keeping with parallel advances in electronics for almost 30 years. A model called the Sackbut Synthesizer, completed in 1971, was launched commercially but met with little success in a market saturated with more visible synthesizers marketed by Moog, Arp, EMS, and Buchla. Tragically, Le Caine died in 1977 at the age of 63 from injuries suffered in a motorcycle accident before having an opportunity to fully realize the potential of the Sackbut in a market that had finally caught up with his innovative ideas.

The Electronic Sackbut used voltage control techniques to trigger and modify sounds. The Sackbut had a familiar-looking keyboard for the control of pitch in addition to several specially devised touch-sensitive controls for other sound parameters. The keys of the manual were spring-mounted and pressure-sensitive so that the volume of the sound would increase with the force being applied to them. A gliding transition between adjacent keys was achieved by pressing a key sideways toward the next higher or lower key. With a little practice, this effect could be accentuated to take on a portamento glide by releasing the first key and then quickly pressing a series of additional keys up or down the scale.

The type of waveform and timbre was modified using a touch-sensitive pad for the left hand that had individual controllers for each finger. Because the hand could remain in a stationary position, the dexterity and practice needed to effectively play the controls was greatly minimized. All selections could be made with the fingers and thumb. The thumb had two pads for controlling the balance of overtones in a note: one controlled the dominating frequencies, or "main formant," of the waveform, and the other

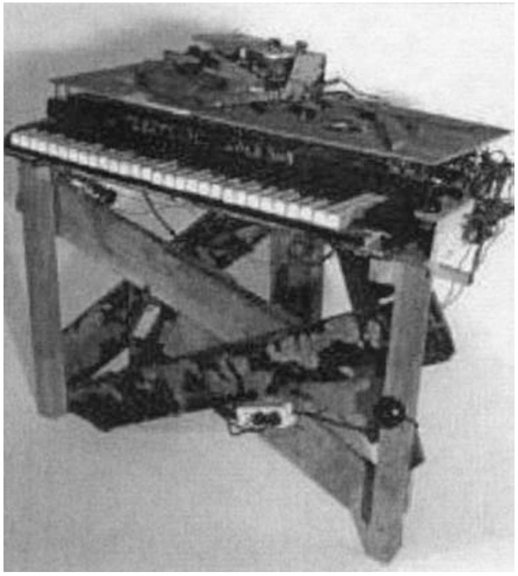


Plate 6.14 Electronic Sackbut prototype, invented by Hugh Le Caine in 1948. This was the first voltage-controlled analog synthesizer. (© Hugh Le Caine Archive, National Research Council Canada)

controlled the "auxiliary formant." The index finger rested on a movable circular pad that could be pressed in any direction to continuously change the waveform and timbre of the sound. This deceptively simple controller provided the player with extraordinarily fluid manipulation of the waveform. The oscillator provided sawtooth and pulse waveshapes. The pad was marked so that the musician could equate locations on the pad to various approximations of tonal quality, such as the reedy timbre of an oboe, the brassy sound of a trumpet, or the more purely abstract "foundation tones" of the oscillator. The remaining three fingers of the hand each had a pressure pad that could be pressed to modify the strict "periodicity" or regularity of the waveform, resulting in surprising and sometimes unpredictable changes to the tone.

Le Caine's success and popularity with musicians was the result of his interest in developing instruments with intuitive and easy-to-learn controls. The Electronic Sackbut, although monophonic, was conceived with enough synthesizing flexibility to serve as "the starting point of all musical thinking."[46]

Touch-Sensitive Organ (1952–57)

Another early Le Caine project was the creation of the first pressure-sensitive keyboard for an electronic organ. Although regarded as a standard feature on even the least expensive electronic keyboard instruments today, his invention of a keyboard whose output volume would vary in proportion to how hard the keys were pressed was a couple of decades ahead of its time. A prototype was made of this organ and the rights to the patent were acquired by the Baldwin Organ Company in 1955, but a commercial model was never mass-produced.[47] Le Caine himself sometimes used the Touch-Sensitive Organ as an audio source for his own tape compositions, as in his piece *Ninety-Nine Generators* (1957).

Special Purpose Tape Recorder (1955–67)

Otherwise known as the "Multi-Track," this was Le Caine's early version of a tape recorder capable of recording and mixing multiple individual tracks. Monophonic recording was still the industry standard when he first produced a six-track version of the machine. Unlike later multitrack recorders—and Raymond Scott's invention from two years earlier—the Multi-Track did not record its sound using multiple tape heads and a single reel of tape. Instead, Le Caine's device synchronized the playback and recording of six individual tape reels. The sound from all six was mixed down into a single track. It was possible to control the variable speed of each of the six tapes independently of one another, making the recorder ideally suited for tape composition of electronic music. The speed of each tape was controlled by a touch-sensitive, 36-key keyboard, providing preset speed changes in small, incremental steps. In practice, the keyboard-controlled feature of the tape recorder was an excellent tool for the composer, providing a measurable degree of control over speed transposition that would not have been easily achieved through conventional variable control or clutch-driven tape recorders. Le Caine demonstrated the utility of this device to the composer when he created his own work *Dripsody* (1955), the sound material for which was based largely on the sound of dripping water transposed to different speeds. The Special Purpose Tape Recorder was a key component of the University of Toronto Electronic Music Studio when it opened in 1959.[48] Le Caine refined the device over the years, eventually making a more compact, solid-state version in 1967.

Oscillator Banks (1959–61) and the Spectrogram (1959)

Le Caine built several versions of a device for controlling and experimenting with multiple audio oscillators. Each had a touch-sensitive keyboard for triggering the individual oscillators, each of which could be tuned and switched to play sine, pulse, and sawtooth waves. He built versions of the oscillator bank with 12, 16, 24, and 108 oscillators. In addition to the touch-sensitive keyboard controller, the oscillator bank could be programmed using an optical reader called the Spectrogram. Le Caine invented the Spectrogram to enable the graphical input of program instructions—a uniquely artistic method of sound programming even to this day. Images were fed into the Spectrogram using a roll of paper and scanned using an array of 100 photocells. Le Caine's interest in the optical input of graphic information to be used for composing purposes paralleled similar interest at both the Columbia–Princeton Electronic Music Center and the Siemens Studio für Elektronische Musik in Munich.

Serial Sound Generator (1966–70)

This forerunner of analog sequencers used hardwired switches to program a series of tones and related effects. Essentially, it was an analog computer dedicated to the programming of musical sequences. It gave the composer control over the pitch, duration, timbre, and repetition of sounds, and used a voltage-controlled oscillator as its sound source.

Sonde (1968)

The Sonde was another Le Caine instrument dedicated to controlling a large number of sine wave generators. In this case, it had 200 signals available, controlled by a panel of slide controls, one for each tone. Transistorized circuits greatly reduced the space needed to house all of this gear; the Sonde stood four feet high and two feet wide, giving it a much smaller footprint than Le Caine's earlier oscillator banks.

Polyphone Synthesizer (1970)

At the height of the monophonic Moog craze, Le Caine sat down to design what would become one of the most powerful and least-known analog synthesizers of all time.

INNOVATION

HUGH LE CAINE—THE MUSICAL INFLUENCE OF AN INVENTOR

Even though Le Caine's inventions were never mass-marketed like those of Moog and others, his influence was nonetheless significant because his ideas and equipment were used every day by a host of composers and technicians who frequented the electronic music studios at the University of Toronto and McGill University.

Even though he completed over a dozen tape pieces, Le Caine never considered himself a serious composer. This, despite the fact that he composed one of the most famous examples of *musique concrète*—the two-minute *Dripsody* (mono 1955, stereo 1957). His "étude for variable-speed tape recorder" consisted of tape manipulations of a single sound: a drop of water falling into a bucket. He transformed the sound of the drip into a series of pitched notes by adjusting its playback speed and re-recording it. For many years, *Dripsody* was undoubtedly the most often played tape composition in any college music course.[49]

In 1966, Pauline Oliveros had been working with tape delay techniques in the San Francisco area, where she lived. The equipment at the San Francisco Tape Music Center consisted largely of a cleverly patched-together amalgam of tape recorders, oscillators, and filter banks. That summer, she went to Toronto to study circuit-making with Le Caine for two months, and while working there she suddenly found that she had access to some of the most innovative and sophisticated electronic sound processing and recording equipment available anywhere. "The techniques that I had invented for myself were very well supported by the studio setup at the University of Toronto," explained Oliveros. "He [Le Caine] was a very generous man and wished to share his knowledge. I worked with some of his devices there—like the twenty-channel loop machine. But most of my work was done with my own system."[50]

Not surprisingly, Oliveros responded with a deluge of output; some ten completed tape compositions and six ultrasonic tape studies in just a few short weeks.[51] Among these was one of her best-known electronic works, the 21-minute *I of IV* (1966), featuring tape delay and 12-tone generators connected to an organ keyboard. The keyboard and oscillators were already set up that way in the Toronto studio and were evidently one of the versions of Le Caine's various "oscillator bank" permutations, this one having been installed in 1961. Oliveros did what came naturally to her: she pushed "the edges as far as possible."[52] Le Caine's studio instrumentation was clearly invented with the sound sculptor in mind.

Le Caine's contributions to electronic music are often overlooked because he was content with the role of being a behind-the-scenes person, allowing the spotlight to fall on the musicians with whom he worked. He refused to take himself too seriously. This comes through loud and clear in his recorded demonstrations of several of his inventions, including a performance of his piece, *The Sackbut Blues* (1948):

> When a composer writes a piece of music, he attempts to induce in the listener a specific mood or feeling. Here it is a mood best characterized as "low down." I think you will agree that a new peak in "low downness" has been achieved.[53]

The voltage-controlled instrument was built for the McGill University Electronic Music Studio and was fully polyphonic—a feature that other makers of voltage-controlled synthesizers would not introduce for several more years. Like the Minimoog that also appeared in 1970, the instrument was compact with many sound-shaping modules built in. Unlike any other synthesizers available at the time, however, the Polyphone had touch-sensitive keys and individual pitch and waveform controls for each key. Le Caine was able to include these capabilities by giving each of the 37 keys its own dedicated oscillator.

SUMMARY

- The conceptual and technical building blocks that would figure significantly in the development of the commercially available analog synthesizer took shape during the 1940s and 1950s with the increasingly sophisticated approach to synthesis developed by institutional electronic music studios.
- The Olson–Belar electronic music composing machine introduced binary programmability, through the use of punched paper tape, as a control element in the creation of electronic music.
- The RCA Mark II Electronic Music Synthesizer was provided for use to the Columbia–Princeton Electronic Music Center in 1959. Although its programmable composing feature was only used by a select few composers, the machine included a robust set of sound modification features, including multitrack tape recording, pitch, timbre, and envelope control, and an advanced filtering system for altering the quality and pitch of source audio signals.
- The modular design of the RCA Mark II Electronic Music Synthesizer and associated technology were precursors of solid-state analog synthesizers of the 1960s.
- The Columbia–Princeton Electronic Music Center was the first notable university-based electronic music studio in North America, and provided access to equipment for composers and students.
- The Siemens Studio für Elektronische Musik in Munich, which developed parallel to the Electronic Music Center at Columbia University, was another well-equipped facility with programmable control over wave generators and a wide variety of audio processing features. Although not designed from the ground up as an integrated synthesizer like the Olson–Belar RCA synthesizer, the equipment at the Siemens Studio für Elektronische Musik offered many of the same advantages and modularity in the process of creating music.
- Developments at both the Columbia–Princeton Electronic Music Center and the Siemens Studio für Elektronische Musik represented a bridge from the purely electromechanical synthesizer to voltage-controlled instruments that permitted improved programmability for the composer.

- Raymond Scott was a commercial musician and inventor of electronic musical instruments whose work was largely devoted to the making of music for films and television commercials. His inventions included a modular composing synthesizer, a multitrack tape recorder, and a programmable analog sequencer.
- Hugh Le Caine developed the first voltage-controlled synthesizer, the Electronic Sackbut, and designed the key audio components found in the electronic music studios of the University of Toronto and McGill University. His other achievements included the invention of the first touch-sensitive keyboard for an electronic organ, multitrack tape recording devices, an analog sequencer, and banks featuring controllable multiple oscillators.

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KEY TERMS IN CHAPTER SIX

synthesizer	142
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Olson–Belar electronic music composing machine	143
RCA Electronic Music Synthesizer	144
portamento	144
sine waves	145
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voltage control	160
voltage-controlled oscillator (VCO)	161
sequencer	164

MILESTONES

Early Synthesizers and Experimenters

Technical and scientific	Year	Instruments
– Homer Dudley of Bell Labs invented a means for controlling audio processing equipment voltage control.	1939	– The Dudley vocoder included voltage-controlled envelope and amplifier through components.
– Hugh Le Caine developed the first voltage-controlled synthesizer prototype.	1945	– Hugh Le Caine introduced his prototype synthesizer, the Electronic Sackbut.
– Transistor invented at Bell Labs.	1947	
– Olson and Belar invented the electronic music composing machine.	1950	
– Hugh Le Caine invented the touch-sensitive keyboard.	1952	– Hugh Le Caine introduced the Touch-Sensitive Organ.
– Raymond Scott invented the Multitrack Tape Recorder.	1953	
– Electronic music experiments began at Siemens corporation in Munich, Germany.	1955	– RCA Mark I Electronic Music Synthesizer demonstrated in Princeton. – Hugh Le Caine introduced the Special Purpose Tape Recorder.
– Columbia–Princeton Electronic Music Center founded.	1958	– RCA Mark II Electronic Music Synthesizer installed at the Columbia–Princeton Electronic Music Center; a multitrack tape recorder and punched paper reader enabled composers to compose multivoice electronic works that could be played in real time.
– Siemens Studio für Elektronische Musik opened its doors to outside composers. – Harald Bode developed a voltage-controlled amplifier. – Hugh Le Caine invented the first of many series of oscillator bank controllers.	1959	– The Siemens studio included four paper tape readers for controlling sound composition,a vocoder for filtering and shaping source signals, and multitrack mixing. – Raymond Scott introduced the Clavivox electronic keyboard and Electronium composition and performance synthesizer.
– Composer Vladimir Ussachevsky gave Robert Moog a specification for a voltage-controlled envelope generator.	1965	– The Ussachevsky/Moog voltage-controlled envelop generator was built for the Columbia–Princeton Electronic Music Center and also became the basis for envelope generation on Moog and other analog synthesizers.

Technical and scientific	Year	Music and instruments
	1966	– Hugh Le Caine introduced the Serial Sound Generator, an analog sequencer.
	1970	– Hugh Le Caine introduced the Polyphone Synthesizer.