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Live-Electronic Music

GORDON MUMMA

This book begins and ends with an account of the speculations, technological innovations, and occasional bold inspiration that mark the history of electronic music. But the opening and closing chapters are in fact very different histories. Otto Luening looks back from the vantage point of a man who has personally witnessed the march of electronic technology from a point near its beginnings; he is a traditionally schooled composer who has gradually absorbed elements of this technology into an already-formed set of compositional attitudes and skills. For Gordon Mumma, on the other hand, electronic technology has always been present, the object of an absorbing curiosity and interest.

In a sense Mumma's history resumes where Luening's leaves off, examining the developments in electronic music before 1950, not so much as extensions of still earlier technological precedents but, rather, as aspects of the economic and social history of the period. From this viewpoint he considers various kinds of live performance with electronic media; surveys collaborative performance groups and special "heroes" of engineering; and explores in detail the influence of the new technology on pop, folk, rock, and jazz music as instruments are modified and the recording studio makes radical transformations of the original recorded sound. In the last section of the chapter, he discusses the extension of electronic technology into other live-performance arts, which involve sound sculpture, television, lasers, biophysics, and multimedia.

Gordon Mumma, one of the organizers of the ONCE Festival, is a composer and performing musician with the Merce Cunningham Dance Company and the Sonic Arts Union. He has been a consulting engineer for several electronic music studios, and has designed equipment for numerous live-electronic music applications. He has been a lecturer in residence at the University of Illinois, Brandeis University, the State University College of New York at Buffalo, and the Universities of California at Berkeley and Santa Cruz. His articles on contemporary music and electronic music have been published in several languages. His music is published by BMI Canada and has been recorded by Advance, CBS France, Mainstream, and Odyssey records.

INTRODUCTION

The history of electronic music begins with live-electronic music. The events of that history closely parallel, and are often dependent upon, the history of science and technology. Social and economic factors are often of critical importance. During the nineteenth century science and technology, and particularly the concept of electricity, were first applied on a broad scale to industry and commerce. In the second half of that century electrical science was applied to communications: as a result, the telegraph, the telephone, magnetic recording, and motion pictures were born.

The telegraph and telephone are means of immediate communication of information. Magnetic recording and motion pictures are means of delayed communication; they store information that is to be communicated later. For various social, economic, and technological reasons, the technology of immediate communication developed more rapidly than that of delayed communication. Though a patent for magnetic recording was issued to Valdemar Poulsen in 1898, this device was not generally used until the late '40s, following its technological development by the Germans just previous to the Second World War.

It is a common premise that electronic music became a reality because the magnetic tape recorder allowed a composer to work directly with stored sound. This premise thus places the beginnings of electronic music after the Second World War. But from 1885 on, patents for electrical and electronic music apparatus were issued at an accelerating rate. Much of this apparatus was to be used for live musical performance. Thus, we more rightfully place the beginnings of live-electronic music, at the latest, at the end of the nineteenth century.

LIVE-ELECTRONIC MUSIC BEFORE 1950

Technological, Economic, and Social History

One of the earliest electrical music instruments was patented in 1885 by Ernst Lorenz. It was an electromagnetic resonator controlled by a vibrating metal bar and a hammer. The principle is similar to that used in several present-day electronic pianos, and is related to various recent techniques of filtering and envelope control. However, before the turn of the century two other names are more important: William Duddell, an English physicist, and Thaddeus Cahill, an American lawyer.

Duddell's contributions were both theoretical and practical. In 1899 he demonstrated the transmission of sound by means of carbon arc lamps, and performed these "singing arcs" by means of oscillating circuits controlled from a keyboard. The significance of the "singing arcs" was that it enabled more than one person at a time to hear electrically produced music. The moving-coil loudspeaker, though patented one year earlier, was not developed for

general use until 1926. Before that time the usual way of listening to electrically produced music was by telephone receivers. In 1900 Duddell formulated a theory for the negative-resistance oscillator, which was applied years later to neon bulbs and vacuum tubes in various electronic music instruments.

The musical use of the telephone brings us to the incredible Thaddeus Cahill. In the fifteen years between 1892 and 1907, Cahill designed, patented, and built a musical apparatus that, in certain respects, remains unsurpassed more than a half-century later. This apparatus, called the Telharmonium, was an electronic music synthesizer that could be performed live over the telephone system. The Telharmonium cost nearly a quarter-million dollars (in pre-First World War currency), weighed about 200 tons, and occupied the entire basement and first floor of a building at 39th St. and Broadway in New York City. It also set a precedent of sorts for a present-day requirement of live-electronic music instruments: portability. At one time in its existence the Telharmonium was transported in thirty railroad freight cars from Holyoke, Massachusetts to New York City, where it was installed in its Broadway home, called "Telharmonic Hall, the First Central Plant of the New York Electric Music Company." For its time the Telharmonium was an unusual technological achievement. Consider the fact that electronic amplification did not exist until Lee De Forest invented the "audion," a triode vacuum tube, in 1906, and that vacuum-tube amplification was not commercially feasible until after the First World War.

In the process of controlling sound electronically, there are many inherent losses in amplitude. Since amplification was not available to Cahill at that time he had to use other means of overcoming this problem. He overcame the amplitude losses of the system by building alternators that produced more than 10,000 watts, used these as his sound generators, and mixed his sounds with enormous multi-tapped transformers. Remarkably, he achieved many of the basic electronic music procedures used today—sustained oscillation, frequency control and filtering, envelope shaping, and mixing—by the use of a single phenomenon: inductive reactance. He built synchronized alternators with such accuracy that his Telharmonium could be performed with a variety of intonation systems besides that of equal temperament. Cahill's interest in intonation was part of an exploration from which he devised a system for the objective measurement of sound that was a predecessor of information theory. The Telharmonium had a frequency range of nearly seven octaves, almost twice as much as the best acoustic recordings of the time. The Telharmonium was a multiple-keyboard instrument, usually played by two performers, "four-hands." The performers presented a repertory of the respectable music of the day (Bach, Chopin, Gounod, Grieg, Rossini, etc.) on regularly scheduled programs. One could visit Telharmonic Hall to hear these programs or subscribe to a telephone circuit to hear them elsewhere. The New York Electric Music Co. was a predecessor of Muzak.

Besides representing a technological state-of-the-art, Cahill's Telharmonium was an economic and social product of its time. The scale of financial investment required was representative of capital expansiveness in the United

States at the turn of the century. Cahill's idea seemed like a good investment for many reasons, not the least of which was the detail and comprehensiveness of his patents. His creative contemporaries may have had equal scientific and artistic imagination, but few had Cahill's legal experience in securing patents.

The years from 1907 to 1919 saw very little electronic music activity. But the telephone industry was hard at work on technological development, particularly the process of electronic amplification.

In 1920 the Russian Leon Termen introduced his "Theremin" in Leningrad. The Theremin relied entirely upon sustained oscillations achieved by a vacuum-tube beat-frequency oscillator. This instrument is not performed from a keyboard, but, rather, is controlled by the indigenous interaction of human-body capacitance with the instrument itself. For several decades the Theremin was performed world-wide by a number of virtuosos, and is still used today in its updated transistorized versions.

Several other live-electronic music instruments were invented in the '20s, among them Jörg Mager's "Sphärophon," Maurice Martenot's "Ondes Martenot," René Bertrand's "Dynamophone," and Friedrich Trautwein's "Trautonium." The "Trautonium" was unusual because of its use of subtractive synthesis for sound production; it is still used in Germany in modified versions. The "Ondes Martenot," introduced in Paris in 1928, became the most widely known. Some of these instruments employed a moving-coil loudspeaker, and were thus freed from the use of telephone audition in traditional concert situations. The electronic music instruments of the '20s were not necessarily considered commercially feasible for mass production by their inventors—this despite the public enthusiasm, particularly in the late '20s, for the new products of affluence: radios, electrical recordings, appliances, and automobiles.

However, one man—Laurens Hammond—was definitely interested in commerce. Just before the Wall Street disaster of 1929 Hammond established, in Evanston, Illinois, a company to build electric organs. The Hammond organs of the '30s were remarkable instruments. They were attractive because by electronic means, they achieved in a smaller package at much less cost something of the effect of the glamorous pipe organs. To the purist the Hammond organ was a disgrace. But enough buyers were found during the economically precarious '30s to enable Hammond to stay in business, patent several basic procedures, and establish his instrument as a household word.

In certain technical and musical respects the Hammond organ is still a very interesting electronic organ. The purists were right: it didn't sound like a pipe organ. But the unique drawbar system of additive timbre synthesis (fundamentally an efficient extension of Thaddeus Cahill's Telharmonium) places the Hammond organ in the category of live-electronic music synthesizers. Among other achievements, Hammond accomplished stable intonation (a constant problem for electronic music instruments of that time) by another practical extension of a Cahill principle, synchronized electromechanical sound generators. Hammond also patented a procedure of electromechanical reverberation that used the helical torsion of a coiled spring, which is widely used today in many electronic music applications.

By the late '30s Hammond had competition, including the English Compton Organ, the Canadian Robb Wave Organ, and the "Bourne Electric Pipe Organ." In spite of an economic depression, the electronic organ had become the first widely used electronic music instrument, and it held a firm position in the "leisure market."

Among other technical achievements of the '30s were the first demonstration of television transmissions and several important developments in magnetic recording. The first of the latter was the discovery of alternating current (AC) bias, a procedure that mixes a supersonic current with the audio signal during recording. AC bias helps to minimize distortions that are inherent in the magnetic recording process. Following a German prototype of magnetic tape demonstrated by Fritz Pfleumer in 1927, I.G. Farbenindustrie (part of the cartel that included the BASF firm) developed the first practical oxide-coated plastic tape in 1932. In conjunction with the German industrial cartel AEG, the prototypical magnetic tape recorder called the "Magnetophon" was introduced at the 1935 Berlin Radio Fair. At the BASF Ludwigshafen factory in 1936, the first magnetic tape recording of a symphony orchestra was made; the London Philharmonic Orchestra performing Mozart. Other kinds of magnetic tape recording were being developed at the same time, including the "Blattnerphone" and the Marconi-Stille recorders, both of which were being produced by the late '30s. These two machines used solid steel tape of 3- to 6-mm. width. A reel of tape for the Marconi-Stille machine weighted about 35 lbs. and ran at nearly 60 inches per second. Splices were made by soldering. With the disruption of the Second World War, the artistic implications of magnetic tape were not explored again until the '50s.

Artistic Activity

Of all the live-electronic music instruments introduced by 1935, the "Ondes Martenot" has the distinction of having had a repertory of original music composed for it. Ultimately, it is the repertory of music composed for an instrument that establishes its most secure place in history. In the '30s several well-known composers experimented with the Ondes Martenot; these included Paul Hindemith, Darius Milhaud, Ernst Toch, and Edgard Varèse. One composer, Olivier Messiaen, composed an expansive piece, *Fête des Belles Eaux* (1937), for an ensemble of six Ondes Martenots, which is so musically innovative that it has achieved the status of a major work. (In the same year Percy Grainger composed a geometrically graphic score for an ensemble of four Theremins.) More recently, the Ondes Martenot has been championed by young performers such as Arlette Sibon-Simonovic, who has introduced new works by John Cage, Jose-Maria Mestres-Quadreny, and Bernard Parmegiani.

The future of electronic music was the subject of considerable discussion during the first half of this century. In 1907 the esteemed composer and pianist Feruccio Busoni mentioned electronic music in his "Sketch for a new esthetic of music," making specific reference to Cahill's Telharmonium. Edgard Varèse

wrote and spoke about electronic music, and from 1916 on made repeated, though unsuccessful attempts to organize collaborative efforts. In the '30s Joseph Schillinger, Leopold Stokowski, Carlos Chavez, J. Murray Barbour, and John Cage added their writings and efforts to the subject.

In 1939 John Cage composed the first of a series of live-performance works called "Imaginary Landscapes," which were to be performed with conventional instruments and electronic devices. While working in Seattle, Cage experimented with the electronic equipment of the recording studio at the Cornish School, and composed a part for *Imaginary Landscape No. 1* that required disc recordings to be performed on a variable-speed record player. In 1941 Cage moved to Chicago, where he conducted further experiments at CBS in preparation for a collaborative radio broadcast with the poet Kenneth Patchen. In the *Imaginary Landscape No. 2*, *Credo in Us*, and *Imaginary Landscape No. 3* —all composed in 1942—Cage employed the performing of radio, electric buzzers, amplified marimbula and wire coil, audio oscillators, and variable-speed disc recordings. *Imaginary Landscape No. 3* was introduced to New York audiences at a Museum of Modern Art concert on February 7, 1943.

The impact of the Second World War on the creative arts was brutal; it left as a monument for posterity the spectacle of a fifteen-year gap in the historical continuity of European music. Many creative artists became refugees, thus adding to their usual struggles for survival the problems of new languages and customs in adopted lands. In an era of instantaneous communication, the dissemination of new music and ideas had become extremely difficult. The remarkable last works of Webern and Schönberg, and in particular the most innovative music of John Cage and the young Pierre Boulez, were refracted through this gap to meet their audiences as much as fifteen years later. Technology was directed toward war, with the ironical effect of accelerating innovation while restricting application. With an occasional exception, the momentum of interest in electronic music was suspended until the future. Two years after Cage's *Imaginary Landscapes* of 1942, Percy Grainger and Burnett Cross constructed an instrument of eight synchronized oscillators for the composition of "free music."

It was a few years after the war ended before experimental work resumed. In Paris in the late '40s Pierre Schaeffer and Pierre Henry began their experiments with disc recorders at the French Radio, and Paul Boisselet composed a series of live-performance works for instruments, tape recorders, and oscillators. In 1949 the German engineer Harald Bode built the electronic Melochord, and Oskar Sala modified the Trautonium and its original live-performance function—the result was the Mixtur-Trautonium, which was used to compose film soundtracks. The musical instrument firm of Hohner began producing various popular electronic musical instruments in Trossingen. In Canada, engineer Hugh Le Caine, working for the National Research Council, began in 1948 a long career designing electronic music instruments. Between 1945 and 1950 the tape recorder was introduced to the United States, the first production units being modeled after the German war booty "Magnetophon."

The appearance of the tape recorder engaged virtually the entire attention of the American composers interested in electronic music, with Louis and Bebe Barron beginning their tape experimentation in 1948.

LIVE-ELECTRONIC MUSIC SINCE 1950

The general availability of the tape recorder a few years after the Second World War stimulated a rapid increase in electronic music activity from 1950 on. Magnetic tape was the first storage medium for sound which was reasonably editable: it could be accurately cut and spliced. During the '50s most composers treated magnetic tape in a manner analogous to that of filmmakers working with film. As with film, tape music was "composed" largely through editing. Until 1960 there were very few exceptions to the use of tape as a studio medium, though it was a vastly more relevant use than is usually implied in the term "canned" music. These exceptions began to appear in the late '50s and increased rapidly throughout the '60s. Some composers used taped sound in live concert with instruments or voices. Others explored the use of tape in innovative performance situations without referring to traditional music; or they developed real-time studio techniques that were in themselves live performances, using tape only to record the result for distribution.

More significantly, some composers discarded the tape medium as a musical premise and explored the use of electronic devices, separately and in conjunction with acoustic instruments, as a basis for live-performance. Finally, digital computers became increasingly valuable tools for musical composition and sound synthesis, and by 1970 were variously applied as live-performance instruments.

Live Performance of Instruments with Tape

Composers that use magnetic tape continuously experiment with ways to present their work to audiences. Broadcast and recording are successful because they allow the audience to determine for themselves the formality (or informality) of how they listen. Playing tapes for audiences in the concert hall is another matter. The concert audience has strong traditional expectations. Audiences expect to see as well as hear a performance, and loudspeakers aren't much to look at.

Furthermore, many composers who work with tape still compose for conventional instruments and have specific ideas on how to combine the media. One of the first combined works has become a classic. Edgard Varèse's remarkable *Déserts* (1949–52) alternates between conventional instruments and taped sounds, producing the effect of a monumental sound sculpture. However, by the mid '50s two collaborative compositions by Otto Luening and Vladimir Ussachevsky had become better known. Their *Rhapsodic Variations* (1953–54) and A *Poem in Cycles and Bells* (1954) had reached the American public through broadcast and recording.

The Luening-Ussachevsky works were composed in New York City. Parts

of the Varèse *Déserts* were done in Paris, where before 1955 other works for instruments and tape had been composed by Paul Boisselet, Pierre Henry, Andre Hodier, Darius Milhaud, and Pierre Schaeffer. From 1955 to 1960 the repertory for instruments and tape was increased by works from Belgium (Louis de Meester, Henri Pousseur), England (Roberto Gerhard), Germany (Mauricio Kagel, Karlheinz Stockhausen), Italy (Luciano Berio, John Cage, Luigi Nono), the Netherlands (Henk Badings), Japan (Kuniharu Akiyama, Shin Ichi Matsushita, Makato Moroi, Joji Yuasa), and the United States (Richard Maxfield, John Herbert McDowell, Gordon Mumma, Robert Sheff, Morton Subotnick). In the '60s works for this medium came from Argentina, Australia, Austria, Brazil, Canada, Czechoslovakia, Denmark, Finland, Greece, Iceland, Israel, Mexico, Poland, Spain, Sweden, and Yugoslavia as well.

The sounds composed on tape had many acoustic and electronic sources. A few composers, however, were more interested in electronic synthesis than in tape composition. For Milton Babbitt magnetic tape was primarily a way of storing the music that he had composed with the RCA Mark II Synthesizer. Babbitt also synthesized music that was stored on tape but was intended to be heard in live performance. His *Vision and Prayer* (1961) and *Philomel* (1964), both for soprano and synthesized sounds, are examples.

The ways of combining instruments with tape are diverse, and the methods of coordination are particularly interesting. In Luciano Berio's *Differences* (1958–60) and Mauricio Kagel's *Transicion II* (1958–59), the tape and instrumental sounds occur in ensemble. Being derived from the instruments themselves, the tape sounds at times like a natural extension of the live instruments. Mario Davidovsky, in his *Three Synchronisms* (1963–65), and Roberto Gerhard, in his orchestral *Collages* (1960), use taped sounds of electronic origin as well, and contrast is very specific.

Except for sophisticated experimental tape machines, where specific coordination is required, musicians must follow the tempo established on the tape. Some composers have invented special notation for the tape-stored sound and have added it to the musical notation of the instrumental parts. Over reasonably short durations, even with complex tape sounds, instrumentalists have found it practical to learn the tape "by ear," so that in Davidovsky's *Synchronisms,* for example, very strict timing is achieved. Another synchronizing procedure uses a special track of multi-channel tape for cues that the instrumentalist hears through headphones. An early example is Ramon Sender's *Desert Ambulance* (1964) for amplified accordion, stereo tape, and light projection. Sender used a special three-channel tape: two channels contained the stereo sounds heard by the audience, and the third, heard only by the accordionist, contained pitches, timing cues, and spoken instructions. In the *Lyric Variations for Violin and Computer* (1968) composer J. K. Randall synthesized the tape sounds with an IBM 7094 computer, and also had the computer produce a metronome tape heard only by the violinist.

Many live instrument-tape compositions do not require precise synchronization. Indeed, some composers are interested in having the tape and live sounds occur quite independently of each other. A classic example is John

Cage's *Aria with Fontana Mix* (1958). Finally, some works such as Barney Childs' *Interbalances VI* (1964) require the performers to prepare the tape from sounds and synchronization of their own making.

Performed tape

From a collaborative tape-music project established in 1951 by Earle Brown, John Cage, Morton Feldman, David Tudor, and Christian Wolff (with the technical assistance of Louis and Bebe Barron), Cage composed his *Williams Mix* (1952) for eight tracks of tape. The work has a score that constitutes a pattern for cutting and splicing the tapes and that establishes an early premise for treating tape music as a non-fixed medium. Working at the Studio di Fonologia Musicali in Milan in 1958, Cage composed *Fontana Mix* for four tracks of tape. *Fontana Mix* has a score that is used in live performance to modify and distribute the sounds in space. In Cage's *Rozart Mix* (1965), the performers, who may include members of the audience, supply tapes of sounds that are spliced into loops during performance for playing on a large ensemble of tape recorders. Other unusual applications of tape-loops include Alvin Lucier's *The Only Talking Machine of its Kind in the World*, and Daniel Lentz's *Rice, Wax, and Narrative*. In both works very long loops are used; in Lentz's piece the performers are encircled, and in Lucier's the entire audience is encircled.

Robert Ashley's classic, *The Fourth of July* (1960), a tape composition for theater as well as concert presentation, was made in a studio of the composer's own design, which allowed for considerable real-time performance on the equipment. The multi-channel tape of Ashley's *Public Opinion Descends Upon the Demonstrators* (1961) is performed live according to the interaction between a notated score and the audience response. The remarkable work of Richard Maxfield was composed on magnetic tape by his own live-performance studio techniques. Maxfield's *Night Music* (1960), *Amazing Grace* (1960), and *Piano Concert for David Tudor* (1961) have been belatedly recognized, and their technical and musical procedures are now widely imitated.

Employing all sorts of innovative studio procedures, Pauline Oliveros composed in 1966 a series of real-time stereophonic tape compositions, of which *I of IV* is best known. At the same time, Terry Riley developed a live, polyphonic, solo-performance interaction among tape recorders, soprano saxophone, and electric organ, from which compositions such as *Rainbow in Curved Air* (1968) and *Poppy Nogood and the Phantom Band* (1966) were produced.

On commission from NHK in Tokyo in 1966, Karlheinz Stockhausen began his *Solo für Melodieinstrument mit Rückkopplung*. Though open-structured, the form of this work requires precisely fixed time delays achieved by means of a magnetic tape feedback loop. The precision necessary for these time delays was not efficiently achieved until a few years later when a special mechanism of adjustable playback heads was constructed.

Perhaps the most unusual use of magnetic tape as a live-performance

medium has been achieved by Jon Hassell in his works *MAP/1* and *MAP/2* (1969). Hassell composed these works on large sheets of magnetic tape. The performers select from the stored sounds by moving hand-held playback heads across the magnetized oxide surface of these sheets. Because of the large size of this "tape," the composer duplicates the tape by a special process of magnetic contact printing.

Live-Electronic Music without Tape (Amplified Small Sounds, Performed Electronic Equipment)

Electronic amplification had been used in music before the Second World War to make traditional instruments louder and to develop electronic instruments; it was also used by John Cage in his *Imaginary Landscapes*. Cage's use of amplification was prophetic because it was a special sense of magnification. That is, instead of amplifying sounds that were simply not quite loud enough, he experimented with sounds of such small magnitude that without amplification they were practically inaudible. Electronically magnified, these micro-sounds revealed a whole new world of sound resources. At the studio of the French Radio in Paris, this direction was continued in 1952 by Jean Louis Brau in his *Concerto de Janvier*, made directly with microphone effects. But the live-performance implications of this work were missed by the French Radio experimentalists, who continued to work with magnetic tape and disk manipulations.

Following eight years of innovative work with the "prepared piano," Cage resumed composing for live-electronic means with the *Imaginary Landscape No. 4* (1951) for 12 radios with 24 performers. This work and the *Radio Music* (1952), *Speech* (1955), and *Music Walk* (1958) that followed, was an exploration of the radio receiver as a live-performance instrument. After composing *Imaginary Landscape No. 3* in 1942, Cage did not return to the use of microphones until his *Winter Music* and *Variations II* of the late '50s. These two compositions were developed by David Tudor as works for amplified piano. For *Winter Music*, the piano was performed from the keyboard and made ultra-loud; *Variations II* was an exploration with contact microphones that raised the micro-sounds from inside the piano to concert audibility.

In 1957 the members of the *Manifestations: Light and Sound* productions in Ann Arbor began live performances of amplified small sounds, tape music, and light projection. In 1960 John Cage composed the *Music for Amplified Toy Pianos*, which used contact microphones, and the classic *Cartridge Music*, which used phonograph cartridges. These four Cage works were performed widely, particularly by David Tudor and the composer, and were a considerable stimulus to experimentation in live-electronic music. Live performance with amplified small sounds aided by the development of new live-performance electronic equipment, became an important activity during the '60s. It gradually attracted the attention of many who, philosophically committed to the tape medium, had previously dismissed live-performance electronic music as an unworthy endeavor.

Only a few other composers worked with live-electronic music before 1960.

In Ankara, Bulent Arel composed his *Music for String Quartet and Oscillator* in 1957, and in New York, Dick Higgins composed *Graphis 24* (1958), a score for controlling theremins and feedback. In New York, Joe Jones created a marvelous menagerie of electrical, electronic, and mechanical instruments that on occasion could be heard performing by themselves in the lobbies of modern music concert halls.

Between 1960 and 1965 most live-electronic music activity occurred in the United States. It was nourished not only because of a spirited experimental milieu, but also because the benefits of solid-state electronic technology were most accessible in the United States. The Americans who composed for live-electronic performance during these years included Robert Ashley, Philip Corner, Max Deutsch, John Eaton, Alvin Lucier, Gordon Mumma, Max Neuhaus, David Tudor, and La Monte Young. Outside the United States, similar work was done by Takahisa Kosugi in Japan, Gil Wolman in France, Karlheinz Stockhausen in Germany, and Giuseppe Chiari in Italy. From 1966 through 1970 compositions of live-electronic music multiplied rapidly, the majority of activity still in the United States. Live-electronic music compositions were occasionally issued on commercial recordings, and were performed widely enough in concert to establish a sense of repertory for the growing audiences interested in new music

In the repertory of live-electronic music the continuing work of John Cage assumes large proportions. In 1961 Cage composed *Music for Carillon No. 4*, and in 1967, *Music for Carillon No. 5*, thereby completing a series of pieces for electronic carillon that he began in 1952. *Atlas Eclipticalis* (1961–62) is a work for large ensemble with variable electronic modification. *Rozart Mix* (1965) is a participation piece with a large ensemble of performed tape loops. *HPSCHD* (1969), a collaboration with composer Lejaren Hiller, combines fifty-one computer-synthesized tapes with seven electronic and amplified harpsichords in live performance. The series of *Variations* numbered from I to VIII, begun by John Cage in 1958 and completed in 1968, hold far-reaching implications. By various elegant innovations in graphic notation, the composer specified the circumstances and outlined the procedures for each of the *Variations*. These *Variations* are plans for societies of activity, not necessarily limited to musical activity, and as good plans should, they allow for the updating of electronic and other means to achieve their ends.

Closely associated with John Cage, David Tudor has been responsible for much of the technological and performance reification of these works. Paralleling his activities as the major performer of innovative piano music in the '50s, Tudor devoted much of his time in the '60s to proselytizing and to performing and nourishing the live-electronic music of other composers. In the wake of this incredible activity and dedication to others' work, the imposing figure of David Tudor as a composer appeared with his *Fluorescent Sound* (1964), *Bandoneon !* (1966) and *Rainforest* (1968).

Electronic modification of electronically generated sound and electronic modification of acoustically generated sound are the two most common procedures of live-electronic music. The first of these is the basis of commercial

electronic music synthesizers. The second is applied by Tudor in his *Fluorescent Sound*, in which he electronically amplified and distributed the mechanical resonances of the fluorescent light fixtures of Stockholm's Moderna Museet on September 13, 1964. *Bandoneon !* (Bandoneon factorial) was a "combine" of programmed audio circuits, moving loudspeakers, TV images, and lighting, activated by the acoustic signals of an Argentine Bandoneon. For this work Tudor developed special "instrumental loudspeakers" with which he exploited the unique resonant characteristics of sounding physical materials. This concept of the loudspeaker as a musical instrument was further extended in the remarkable *Rainforest*. In this work, however, Tudor applied the second of the two basic concepts above in reverse: it is an example of acoustic modification of electronically generated sound.

The sounds of *Rainforest* are generated by sine and pulse oscillators, and are applied by special transducers to various resonant objects of wood, metal, and plastic. Each of the combinations of transducer and resonant object is an "instrumental loudspeaker" that adds and subtracts harmonics and occasionally creates complex intermodulations with the electronic oscillations. Further, attached to each "instrumental loudspeaker" is a small microphone that allows the acoustically modified sound to be further amplified and resonantly distributed by conventional loudspeakers throughout the performance space. Because the "instrumental loudspeakers" are affected by the sounds of the conventional loudspeakers, a recycling phenomenon takes place that makes the entire electronic-acoustic apparatus of *Rainforest* an ecologically balanced sound system. *Rainforest* is generally performed by two performers and an "orchestra" or "forest" of eight to twelve "instrumental loudspeakers" and four conventional loudspeakers. The performers articulate the electronic oscillators, distribute the oscillations to the "instrumental loudspeakers," and create combinations of "instrumental loudspeakers" that are heard from the conventional loudspeakers. The work has been widely performed by the Merce Cunningham Dance Company, by whom it was commissioned. Tudor has also produced *Rainforest* in an expanded concert version. One of these productions, at the "Chocorua 73" festival in New Hampshire, was implemented by a workshop of nearly twelve people who, collaborating with Tudor, built many new "instrumental loudspeakers" and extended the sound materials to include prepared sounds of non-electronic origin. The Chocorua 73 performance was presented in a large barn as a six-hour environment.

La Monte Young's amplified voices, traditional instruments, and sine-wave oscillators are performed with specific and carefully determined intonation, and are combined in ensembles with the mysterious projections of Marian Zazeela to create sonorous harmonic spectra that are extended in time to produce a music of epic proportions. Max Neuhaus, a virtuoso percussionist, has not only applied complex electronic amplification to the work of other composers—such as Earle Brown's *Four Systems* (1964), Sylvano Bussotti's *Coeur pour Batteur* (1965), and John Cage's *Fontana Mix-Feed* (1965)—but has also developed his own electronic works for public participation. Among these are *Public Supply* (1966), in which the public is invited to telephone a radio

or TV station to have their voices immediately modified and combined in the transmission. In *Drive-in Music* (1967) a series of weather-sensing, low-power radio transmitters were installed along a road in Buffalo, N.Y., so that the commuting public heard the effects of climate and overlapping propagation on their automobile radios. In 1973 Neuhaus installed a more general access environment called *Walk Through* at the Jay Street–Borough Hall Station of the underground New York Transit System.

The live-electronic music of David Behrman has evolved from the technologically elementary (though musically difficult) use of acoustic feedback with conventional instruments in his *Wavetrain* (1966), to the notationally coordinated use of equalization and frequency shifting of instrumental sounds in his *Players with Circuits* (1967), to the technologically elaborate construction of an ensemble of electronic instruments for *Runthrough* (1968). *Runthrough* consists of oscillators, frequency shifters, voltage-controlled amplifiers, and a photo electric sound distribution matrix; it is performed by three or more players with miniature flashlights. Behrman designed the interacting circuit configuration of the piece so that the various actions of the players with their flashlights do not necessarily produce one-to-one musical correspondences. An ensemble situation is created in which the players must deal with elements of social stress as well as the technological and musical issues of *Runthrough*. For his ongoing work, *Homemade Synthesizer Music with Sliding Pitches*, Behrman has built a purely electronic synthesizer. By means of an interdependent configuration of voltage-controlled amplifiers, mixers, DC-level shifters, and thirty-two function generators, either live performance by human operators or automatic performance by the synthesizer alone is possible.

By virtue of their wide performance and acclaim (at least among audiences for new music), several other live-electronic works have become staples of the repertory. Robert Ashley's *The Wolfman* (1964)—for highly amplified human voice with tape accompaniment—and Salvatore Martirano's *L's G.A.* (1968)—performed by a gas-masked actor in an atmosphere modulated by helium, stereo tape, and film projection—have political as well as musical impact, and are unusually popular. Pauline Oliveros' contribution to this repertory is a series of apparently self-sustaining works for amplified apple boxes, including *Applebox* (1964), *Applebox Double* (1965), *Applebox Orchestra* (1966), and *Applebox Orchestra with Bottle Chorus* (1970). Roger Reynolds' widely performed *Ping* (1968) is a multi-media work, after a story by Samuel Beckett, for ring-modulated and electronically distributed instruments (multiphonic flute, motorized piano, harmonium, bowed cymbal, and tam-tam), magnetic tape, and projected images and calligraphy. Reynolds' *Traces* (1969), *Again* (1970), and the very complex *I/O* (1971)—for mimes, vocalists, instrumentalists, projections, and electronic modification and distribution—continue his work with the integration of acoustic and live-electronic procedures.

A significant aspect of the work of Behrman, Neuhaus, Martirano, and others such as David Rosenboom, Serge Tcherepnine and Stanley Lunetta is that these composers design and build their own electronic music instruments. Very few composers consider the creative design of electronic circuits as a

requirement of their craft, though it is already clear that some of the most important innovations in electronic music have been contributed by electronically educated composers. An education in electronics is not mandatory in order to create live-electronic music, particularly since commercial synthesizers have been developed for use in live performance. John Eaton and Max Deutsch were involved early with the use of synthesizers as live-performance instruments. In 1965 Eaton composed and performed works with the Synket, a portable synthesizer developed by Paul Ketoff in Rome. The same year Deutsch composed in the United States two live-performance works that combined the Moog synthesizer with conventional instruments.

Outside the United States, live-electronic music activity had begun in Japan, where Takehisa Kosugi composed *Micro 1* (1961), a work for solo microphone. Beginning in 1967, Kosugi composed several poetic works with the generic titles *Manodharma* and *Eclipse,* which used both radio-frequency and audio-frequency electronics. Toshi Ichiyanagi composed a repertory of works for electronically modified Western and Japanese instruments, including *Space* (1966), *Situation* (1966), *Activities for Orchestra* (1967), and *Appearance* (1967). Ichiyanagi did not design his own equipment; instead he specified the electronic "instrumentation" and configuration of his pieces, much as a composer would enumerate the types and arrangement of conventional instruments for a piece, relying on the performers to supply the equipment and skill. In Italy, Domenico Guaccero introduced his *Improvvisazione 1962* in Rome; from 1964 through 1966 in Florence, Giuseppe Chiari composed a series of live-electronics works using contact microphones; and in 1966 Luigi Nono composed *A Floresta e Jovem e Cheia de Vida* for singers, instruments, and tape with electronic filters.

Of the German composers working with live-electronic music, Karlheinz Stockhausen has achieved much attention—particularly in Europe where most of his compositions are available on recordings—and his energetic efforts as a polemist are notorious. Stockhausen's large body of composition is diverse in style and idea; this is due to his expansive imagination as well as to his considerable facility to absorb the procedures of other composers' work into his own. In these and other respects his position in contemporary music is analogous to that of Maurice Bejart in ballet. Following *Kontakte* (1960) for percussion and magnetic tape, Stockhausen's next live-electronic works were *Microphonie I* (1964), for amplified and electronically filtered tam-tam; *Mixtur* (1964), for five instrumental ensembles with ring modulators; and *Microphonie II* (1965), for chorus, Hammond Organ, and ring modulator. These were followed by *Prozession* (1967), for amplified and filtered chamber ensemble; *Stimmung* (1968), for amplified singers; and *Aus den Sieben Tagen* (1968), for a variable ensemble with indeterminate electronic modification. Perhaps the most interesting of these works is *Aus den Sieben Tagen,* which, employing graphic and verbal notation, has evolved through performance into an attractively lyrical work of many hours duration, similar in scope to the earlier *Treatise* (1967), by the English composer Cornelius Cardew.

A younger German composer of promise is the violist Johannes Fritsch,

who, independently of the usual state-radio resources, composed several works for instruments and live-electronic apparatus during the mid '60s. These include *Partita* (1965–66), for viola, contact microphone, tape, and equalization, and *Violectra I, II, and III* (1971–72), for Viola d'amore with EMS Synthi. Fritsch is a member of the independent German group "Feedback," organized in 1970, whose members also include Peter Eötvös, Rolf Gehlhaar, David Johnson, Mesias Maiguashca, John McGuire, and Michael von Biel. Several of the members of Feedback were associated with the live-performance ensemble at WDR (the West German Radio) during the years 1967–70, when many of Stockhausen's live-electronic works were recorded. They left the WDR ensemble following performances at EXPO 70 in Osaka because of growing ideological differences with Stockhausen.

A recent and unusual development of live-electronic music in the United States is exemplified by the works of Philip Glass and Steve Reich. Following a direction implied by the earlier work of LaMonte Young and Terry Riley, these composers have developed skilled performance ensembles that often combine acoustic instruments with electronic instruments used in rock music, such as the electric piano, combo organ, and electric harpsichord. Their compositions manifest a strong rhythmic and melodic basis, though the rather elegant style of the works is a fundamental departure from that of rock music.

Live Performance with Digital Computers

The digital computer is a configuration of logic modules to which is added an enlarged memory and various access and control functions. It is a general-purpose device that can be applied to specific problems by means of external programming. Logic modules are most commonly designed for specific functions in live-electronic music equipment, and are not externally programmable to any great extent. With integrated circuitry, logic modules can become relatively involved, as in the 16-bit digital computer/decoder used in Stanley Lunetta's *Moosack Machine*. Logic modules can, in fact, be designed with memory functions, and can be externally programmed. One reason digital computers have found limited use in live performance is their unportable size. Either the live performance must be taken to the computer, or it must be connected to a remote computer by a data-link. A common data-link is a telephone line, with the computer at one end and a teletype among the live performers at the other.

This procedure was used for my own work, *Conspiracy 8* (1970), which was performed live at the Guggenheim Museum in New York City, using a PDP–6 computer in Boston. Using a data-link, the remote computer received information about the performance, made decisions according to a basic program, and issued instructions to the performers. The computer participated as a decision-making member of the ensemble, and the ensemble accepted the sounds of its electronic decision-making—which were relayed to New York City by a second data-link—as a sonic contribution to the music.

For several years Salvatore Martirano has been working on a live-perform-

ance electronic music instrument derived from digital computer procedures. Early in his experimentation, he interconnected two portable digital-logic education modules and used them to articulate an ensemble of electronic oscillators. Though they contained no memory, direct access to the programmable functions of these machines allowed Martirano to treat them as live-performance instruments. During the course of his work he has performed with this continually evolving instrument. One of these performances had the bluntly descriptive title *Let's look at the back of my head for a while* (1970). The instrument has come to be known as the Sal-Mar Construction, and the performances that Martirano presents are literally state-of-the-art events.

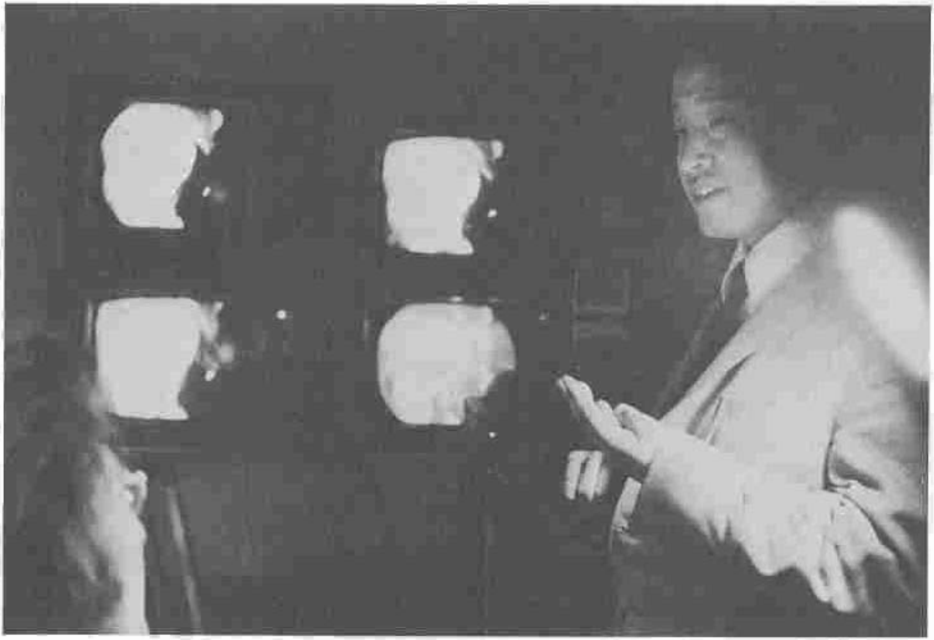
With the recent advent of mini-computers—which include a memory capacity of several thousand words, cost only a few thousand dollars, and occupy only a few cubic feet of space—the digital computer is now a practical live-performance instrument. Edward Kobrin designed a logic-module interface that converts the digital output of his PDP–8 mini-computer into signals that operate voltage-controlled electronic-music modules. His instrument produces six voices simultaneously; each voice consists of a multi-waveform oscillator followed by three filters and an amplifier, all of which are voltage-controlled. The six voices of output are distributed around the performance area by the mini-computer through sixteen loudspeakers. Every aspect of Kobrin's instrument depends upon signals from his mini-computer. With a basic program and micro-routines stored in its memory, the mini-computer is performed live by choosing from the micro-routines. The complexity of the interactions, and the rates of speed with which they can be made, surpass any non-computerized live-electronic musical instrument.

A project with unusual live-performance implications is the digital-computer-controlled electronic music system being developed under the guidance of Jon Appleton at Dartmouth College. This system uses a large time-sharing computer with a satellite mini-computer. To the mini-computer is attached a rack of plug-in, digitally-controlled synthesizer modules. A library of new modules is under continuing development. The user (composer or performer) has access to the system by means of several teletype keyboard and cathode ray tube (CRT) displays, one of which is located right next to the mini-computer and synthesizer module rack in a Dartmouth music practice room. Access is remarkably easy. A single page of instructions enables the user to activate the system. All further questions are addressed through the teletype to the remote time-sharing computer, which displays its answers on the CRT. At this stage, the system functions as a teaching machine that develops the user's programming skills. The user can then compose a program, which is loaded into the mini-computer to operate the synthesizer. The results are heard immediately on loudspeakers in the practice room. Since all the instructions are in simple English, are displayed on a line-by-line basis on the CRT, and operate the synthesizer in real-time, the user can make rapid and exact changes in his work. When the user is through composing, an instruction can be typed by which the program returns from the mini-computer to storage in the time-sharing computer, ready to be called upon in the future. In the meantime,

other persons can use the same practice-room computer satellite for their work. Among the intriguing possibilities of this system are ensemble performances that could be achieved by using several satellites at the same time; or collective or ongoing compositions and performances (perhaps even by an anonymous collective) could be achieved over considerable spans of space and time.

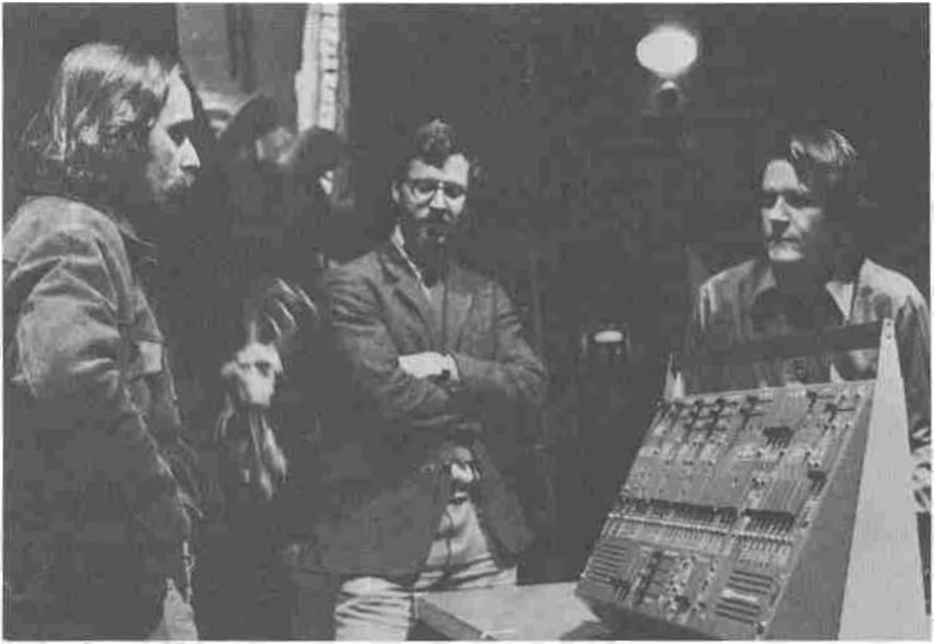
Gordon Mumma building his sound-modifier console for live performance at EXPO 70 in Osaka, Japan. With this console the performers could vary electronically the pitch, loudness, and timbre of eight separate channels of sound from any sources. The modified sound was distributed from a rhombic grid of 37 loudspeakers, designed by David Tudor, in a large mirror-surfaced dome. Photo by Barbara Lloyd.

Violoncellist Charlotte Moorman performing on a video-sculpture musical instrument of artist Nam June Paik. Besides the three television screens which comprise the body of the instrument, the performer is wearing special glasses which support miniature television screens on each side of her head. Photo by Gordon Mumma, Bonino Gallery, New York, October, 1971.



Korean-born video artist Nam June Paik discussing with John Lennon the operation of a video synthesizer designed in collaboration with Shuya Abe. The contours and colors of Lennon's image are modified live by the video synthesizer and presented in different aspects on the television screens in the background. Photo by Gordon Mumma, Bonino Gallery, New York, October, 1971.

David Rosenboom's New York Bio-Feedback Quartet during a performance in New York. The performer at the right has electrodes attached to his head by means of a headband. His electroencephalic signals are applied as control signals for the ARP synthesizers in the background. The performers are, left to right, David Rosenboom, Theodore Coons, Marge Hassell, and Jon Hassell. Photo by Gordon Mumma.



Left to right: Alvin Lucier, Wayne Slawson, and Gordon Mumma during preparation for a live-electronic music concert by the Sonic Arts Union at the Södra Theatre in Stockholm, Sweden, May, 1971. The electronic music equipment at the right is one of two mini-synthesizers used in the performance of Alvin Lucier's *The Duke of York*. Remote-control photograph by Gordon Mumma.

Gordon Mumma, in a performance of his *Hornpipe* (1967) at the Metropolitan Museum of Art, New York, in February, 1972. The electronic equipment attached to his belt is a special-purpose analog computer which analyzes and responds through loudspeakers to the resonances of the performance space which are actuated by the sounds of the French horn. Photo by Ju-may Chu.

A dancer of the Merce Cunningham Dance Company, wearing a telemetry belt for the dance *TV Rerun*. The telemetry belt contains accelerometers which respond to the movements of the dancer, convert the accelerations into audio signals, and transmit them by UHF radio to electronic-music equipment in the orchestra pit. From these telemetered movements the sound score for the dance is generated live in performance and heard by the audience from loudspeakers. Photo by Gordon Mumma.

Left to right: David Borden, Linda Fisher, and Steve Drews, the members of Mother Mallard's Portable Masterpiece Company, performing live with an array of Moog synthesizers at the broadcast studios of WBAI in New York. Photo by Gordon Mumma.

David Tudor and John Cage in a simultaneous performance of Tudor's *Untitled* and Cage's *Mesostics* during its 1972 premiere for the European Broadcasting Union at Radio Bremen in Germany. John Cage alternates between the mixing console, at which he is seated, and the four microphones, where he stands while singing the vocal sections of *Mesostics*. Photo by Gordon Mumma.

David Tudor at the controls of his electronic-music equipment for *Untitled,* during its simultaneous performance with John Cage's *Mesostics.* Much of this equipment was built by David Tudor for his composition *Untitled.* Photo by Gordon Mumma.

Philip Glass (far right) with his ensemble of live-electronic and conventional instruments, performing in New York, February, 1971. Photo by Cynthia Giruard.

Rolf Gehlhaar and Johannes Fritsch of the German group "Feedback" in a broadcast for Hessiche Rundfunk, Frankfurt, in 1971. Besides live-electronic music performances, Feedback also publishes scores and produces collaborative cybernetic environments. Photo by David Johnson.

Peter Eötvös, a member of the German group Feedback, preparing a Drehleier with a contact microphone for a 1972 performance in Darmstadt. The microphones are attached to a portable EMS synthesizer manufactured in England.

Interactions among Technological- and Artistic-Innovation Ensembles and Collaborative Groups

Because of the increasing complexity of technology and the greater facility of group performances (as well as a great attraction to working with multi-media), artists seem inclined to work in collaborative groups more so than in the past. The sharing of resources and ideas has made possible the survival of many artistic endeavors outside traditional institutions of support, and has thereby nourished an unusually roborant quality of creative freedom.

The Cunningham Dance Company is a particularly important collaborative ensemble because (like the Diaghilev Ballet in the earlier part of this century) the collaborations have been sustained over many years and have involved many exceptional creative artists. A list of the composers for the Cunningham Dance Company is a virtual cross section of contemporary music history. Moreover, because the Cunningham Dance Company has performed world-wide, its work has been more readily acknowledged and its influences immediate. Merce Cunningham was probably the first dancer to choreograph with electronic music. In 1952 he presented his "Collage I and II" with Pierre Schaeffer's *Symphonie pour un homme seul,* and in 1953, "Fragments" with Pierre Boulez's *Etude à un Son* and *Etude II.* The dances "Antic Meet" and "Aeon" (1958–61, both with music by John Cage), utilized live-electronic music procedures developed in collaboration with David Tudor. During this time Tudor also produced the spectacular live-electronic version of Cage's *Variations II* (1959). In *Variations V,* created for the French-American Festival at Lincoln Center in 1965, the dancers shared responsibility for the music with the musicians. Two interrelated systems of electronic sensors on the stage detected the movements of the dancers. These sensors were connected to electronic music equipment in the orchestra pit so that the dancers articulated the sound environment of the auditorium as well as the spatial environment of the stage. The decor included projected images by Stan Van der Beek and electronic-sound-producing stage props. The artistic and technological achievements of Cage's *Variations V* have made it a classic of collaborative multi-media.

The performance arts ensemble called the ONCE Group developed from the activities of the ONCE Festival in Ann Arbor, Michigan. Presented annually from 1960 through 1967, the ONCE Festival was a collaboration of architects, dancers, filmmakers, musicians, sculptors, and graphic and theater artists. A repertory of works was created, collaboratively as well as individually, which the ONCE Group presented on tour and for television. These works were artistically and technically experimental, and introduced many innovative live-electronic music procedures. An impetus for the ONCE Group was the multi-media Space Theatre activities that developed around the work of Milton Cohen in Ann Arbor from 1956 through 1964. Cohen established the Space Theatre for live performances of his unusual light-projection art, with the collaboration of architects Harold Borkin and Joseph Wehrer, filmmaker George Manupelli, and several composers. The best-known production of the Space Theatre was the hour-long *Teatro dello Spazio—luce e suono,*

presented at the Venice Biennale in 1964. Besides the activities of the Ann Arbor performers, the ONCE Festival presented many contemporary live-performance artists from elsewhere. It was during the 1964 ONCE Festival that composers David Behrman and Alvin Lucier began their collaboration with Robert Ashley and myself, which led to the organization of the Sonic Arts Union in 1966.

The Sonic Arts Union is a repertory ensemble, working with multi-media on a "chamber-music" scale. Live-electronic music is the predominant activity of this group, which presents its work on performance tours divided about equally between the United States and Europe. Some of the works are collaborative, some are by other contemporary composers (such as Jacques Bekaert, George Cacioppo, and Pauline Oliveros), and some are composed by individuals in the group. The Sonic Arts Union has developed unusually sophisticated and diverse applications of electronic technology to musical performance, and since 1970 has extended its activities to radio broadcasts, television, and recordings.

Mother Mallard's Portable Masterpiece Co. uses studio synthesizers as live-performance instruments, and has developed virtuoso performance procedures for the real-time requirements of concert performance. The equipment of this ensemble consists of five studio-type electronic-music synthesizers mounted in portable cases. The ensemble performs in schools, colleges, and for recordings, presenting a repertory by David Borden, Steve Drews, and Linda Fisher. They also program improvisational situations that foster musical innovation. The ideas of Mother Mallard's Portable Masterpiece Co. have had considerable influence on a major manufacturer of synthesizers. The ensemble puts prototype equipment through rigorous field tests in live performance. They then return important data to the synthesizer designer, thus achieving a particularly beneficial relationship with technological innovation.

In Europe collaborative live-electronic music activity began in 1964 with the Gruppo di Improvvisazione Nuova Consonanza in Rome. This group was an international collaboration (as was the socially and artistically broader conspiracy called FLUXUS), and included the American composers Larry Austin, John Eaton, and William Smith, as well as the Europeans Mario Bertoncini, Aldo Clementi, Franco Evangelisti, Roland Kayn, and Ivan Vandor.

MEV, Musica Elettronica Viva, was organized in Rome in 1966 as a collaboration of mostly American musicians, including Frederic Rzewski, Allan Bryant, Alvin Curran, Jon Phetteplace, and Richard Teitelbaum. The first year of MEV activity consisted primarily of composed music. During 1967 MEV worked deliberately with improvisation, and by 1968 had abandoned formal musical and social structure entirely. Perhaps their most interesting contribution to live-performance procedures was the development of "Sound Pools," a concert situation that encouraged extensive audience participation. MEV maintained a strong precept: to make music with whatever means available. Because of this precept and the slower rate of technological innovation in Italy than in the United States, the MEV members developed general-purpose rather than specialized circuits for live-electronic music. One of these

circuits was a photoresistor mixer designed by Frederic Rzewski, the principal of which has since been applied by composers outside of MEV. Richard Teitelbaum developed live-performance techniques that utilized individual components from the Moog Synthesizer rather than the standard studio configurations. MEV made extensive tours throughout Europe as well as a few performances in the United States. At times the "Sound Pool" concerts included several hundred performers, and the radical influence of the MEV group upon younger European musicians has been considerable.

Of the several British collaborations, AMM, which was formed in 1965, is the best known. Their precepts are similar to those of MEV, but the musical concerns of its early members (Cornelius Cardew, Lou Gare, Christopher Hobbs, Keith Rowe, and Eddie Prevost) seemed more social than technological. These concerns led to the eventual splintering of AMM and the formation of a large open-participation ensemble called the Scratch Orchestra, related in intent to the "Sound Pools" of MEV. Other British groups include "The Gentle Fire" (Richard Bernas, Hugh Davies, Graham Hearn, Stuart Jones, and Michael Robinson) and "Naked Software" (Hugh Davies, John Lifton, Anna Lockwood, Harvey Matusow, and Howard Rees). Both these groups are electroacoustic hybrids and are primarily concerned with experimental and improvisational performance practices. In Australia the innovative ensemble "Teletopa," which includes David Ahern, Roger Frampton and Peter Evans, has attracted considerable attention.

Primarily responsible for the performance of Stockhausen's live-electronic music is the group at the WDR in Cologne, which has included at various times Alfred Alings, Harald Boje, Peter Eötvös, Johannes Fritsch, Rolf Gehlhaar, and Aloys Kontarsky. These are musicians, primarily instrumentalists, whose performance skills extend to electronic modification of their instrumental sounds. In performances of his work, Stockhausen who generally operates filters and amplitude controls, tends to exercise ultimate decisions as to the outcome of the music.

In recent years an intensive collaborative activity in live-electronic music has occurred in northern California. These collaborations, which came after the activities of the San Francisco Tape Music Center in the early '60s, are not easily separated into groups. Rather, this activity is more a geographic phenomenon involving composers from Berkeley, Davis, Oakland, and the surrounding bay area.

A cooperative effort among musicians from the University of California at Davis and Mills College in Oakland was responsible for the First Festival of Live Electronic Music. Presented in December, 1967, the festival comprised concerts, panels, and seminars, and included the work of the "northern California group" of composers Larry Austin, Harold Budd, John Dinwiddie, Anthony Gnazzo, Stanley Lunetta, and John Mizelle, as well as guest composers from other parts of the United States and Japan. Subsequently, Stanley Lunetta became the prime mover of an ensemble called "AMRA ARMA," whose members also include Karl and Kurt Bischoff, Kenneth Horton, and Jeffrey Karl. With a large digital electronic mechanism designed by Lunetta and with substantial percussion resources, AMRA ARMA has developed a

music of Nibelungen proportions and an energy level that is unusually high for California musicians.

A remarkable Japanese collaboration was the Cross Talk Intermedia festival, presented in Tokyo in February, 1969. Organized by Donald Albright, Kuniharu Akiyama, Roger Reynolds, and Joji Yuasa—who enlisted the support of the American Cultural Center in Tokyo and major Japanese industry—Cross Talk Intermedia was attended by capacity audiences in Kenzo Tange's Yoyogi Olympic games facility. The performances included live-electronic and multimedia works of Toshi Ichiyanagi, Takahiko Iimura, Takehisa Kosugi, Yori-Aki Matsudaira, Mieko Shiomi, Toru Takemitsu, and Joji Yuasa, as well as the participating Americans Robert Ashley, Salvatore Martirano, Gordon Mumma, Roger Reynolds, and Stan Van der Beek. If a prize were offered for the best-organized-most-complicated performance collaboration of the century, Cross Talk Intermedia, which smoothly presented six or seven artistically extravagant and logistically disparate works on each day, would be a prime candidate.

Certainly the largest performance collaboration was the ICES 1972 festival, which was presented in London and on a chartered British Rail "Music Train" between London and Edinburgh. ICES 1972 ran continuously in three different parts of London twelve hours a day for more than two weeks in August, 1972. It presented a cross section of live-electronic music from all over the world (excepting only Africa, Antarctica, and Greenland), including a spectrum from rock to academia, as well as dance, video, and conceptual possibilities.

Another kind of activity that is gathering momentum is the combined conference-seminar-workshop-performance format exemplified by projects such as DeBenneville Pines and Chocorua 73. The former was co-sponsored by radio stations KPFA and KPFK, Fluxus West, Source Magazine, and DeBenneville Pines, and was presented in late April, 1973 at a Unitarian Church camp in the San Bernadino Forest of California. Chocorua 73 was a three-week project at a farm-inn in the White Mountains of New Hampshire in June and July of 1973. In both projects a wide spectrum of new music was presented, with particular emphasis on the experimental. Like their predecessors, the ONCE Festival and the San Francisco Tape Music Center, they were also produced with remarkably small budgets independent of "establishment" institutions. Of special significance is the collaborative social and organizational nature of these projects, and the scope of their artistic, technological, and social concerns, which generally surpasses the more parochial "establishment" projects. These newer projects are inherently more inclusive and comprehensive.

Engineering Heroes

Like most endeavors, electronic music has its heroes. Besides certain illustrious composers and performers, there are the guiding spirits of glamorous or well-conceived festivals, such as Roger Reynolds of the spectacular Cross Talk Intermedia in Tokyo; Joel Chadabe, director of the annual festival in Albany; Hans Otte, who for years has directed the prestigious Pro Musica Nova in

Bremen; and Larry Austin, who with his California colleagues produced the historic First Festival of Live Electronic Music in 1967.

Then there are the pioneering inventors and engineers. Generally not composers themselves, they are instead creative artists of circuitry. Like the experimenting composers, their visionary work is often the target of disparaging opinion. Thaddeus Cahill, inventor of the Telharmonium, has become a formidable legend. Celebrated by many, though less well-known by name, is Earle Henry, inventor of the pinball machine and developer of the juke box. Leon Termen and Maurice Martenot are heroes of the infant electronic era between the two World Wars.

Present-day heroes include six "senior" names: Robert Moog and Donald Buchla of the United States, Hugh Le Caine of Canada, Paul Ketoff of Italy, Junosuke Okuyama of Japan, and Peter Zinovieff of England. The name of Robert Moog, who developed the first widely used electronic music synthesizers, has become a household word. Donald Buchla developed the "Electric Music Box," widely used in the western United States and becoming increasingly well-known elsewhere. Hugh Le Caine made early designs of voltage-controlled circuitry, and is responsible for much of the now classic equipment in the University of Toronto electronic music studio. Paul Ketoff designed and built the first portable synthesizer for live performance, which was widely used by John Eaton, and has designed many special-purpose circuits for other composers. Junosuke Okuyama is responsible for the original and remarkable circuits used not only by Japanese composers, but also by visitors to Japan fortunate to have made his acquaintance. Peter Zinovieff founded the firm of EMS, which has produced several generations of synthesizers, including the portable "VCS 3" or "Putney," the "Synthi 100"—which contains a small digital memory—and a more recent system incorporating computer control of both analog and digital devices.

Other engineering heroes in the United States include Dennis Colin and David Friend (who were involved in design innovations for the ARP synthesizers); Harald Bode, Carl Countryman, B. J. Losmandy, Thomas Oberheim, and William Ribbens (designers of special-purpose circuits); and James Beauchamp and James Seawright (designers of electronic-music studios). Outside the United States are the esteemed Marino Zuccheri of the Italian Radio in Milan, Fernando von Reichenbach of the Instituto Torcuato di Tella in Buenos Aires, and the English engineers David Cockerell and Ken Gale, who did the basic design work for Zinovieff's EMS Bournemouth firm. Recently, Ken Gale, with Gerry Rogers and Brian Hodgson, have established their own organization, Rogers Studio Equipments, and are developing a new synthesizer and environmental sound systems. A new generation of electronic engineers, not yet prominent, is already applying state-of-the-art technology to musical experiments.

Technology and Sociology in the Commerce of Live-Electronic Music

The largest audience for live-electronic music, the pop and rock audience, has a speaking familiarity with electronic-music technology. The hardware of this

music has been relatively standardized by mass production, and the custom of most performers is to display it: instruments, wires, electronic devices, and lighting apparatus are strewn around the performance area, visible to everyone.

Among the commercially available electronic devices for musical instruments, amplification is fundamental. The minimal elements for musical instrument amplification are a microphone, amplifier, and loudspeaker. The performer has at least one electronic control—for the amount of amplification—which is generally called "volume" or "gain." It is a simple matter to add circuitry to control the "tone" of the amplified sound. Technically known as equalization, this involves the amplification of some groups of frequencies to a greater extent than others. The treble and bass controls of many amplifiers are an example of equalization.

Because solid-state electronics have made miniaturization of circuits feasible, musical instrument amplifiers often include several other sound-modifying circuits, each with controls that the performer can operate. Tremolo is widely employed. Sometimes erroneously called "vibrato," tremolo is a pulsing, periodic variation in the amount of amplification. Depending on the particular circuit, the rate of periodicity can be fixed or variable, and is generally pulsed in the range from four to fourteen times per second. With some circuits, the performer can also vary the amount of amplification change with a "depth" control. The difference between "tremolo" and "vibrato" is that tremolo is a variation of amplitude, whereas vibrato is a variation of frequency or "pitch." Some electronic organs have a true "vibrato" because it is economically feasible to vary the frequency of the electronically generated sound of an electric organ. Electronic variation of the pitch of acoustic instruments is also possible, but only with sophisticated circuitry that is presently too expensive to justify its use in commercial musical instrument amplifiers. Also, the difference in sound between tremolo and vibrato in many applications is not great enough to have created a demand by musicians for true electronic vibrato.

Reverberation is widely used in musical instrument amplifiers, and is technically interesting because it usually employs non-electronic components to achieve its effect. This effect is an apparent increase in the *space* in which the sound is heard. This is accomplished by making one or more time delays or echoes of the original sound, and mixing the delays with the original sound before final amplification. The performer can control the amount of mixing. The delays are usually measured in milliseconds. To achieve these delays purely by electronic means is extremely costly. Consider that sound travels in air at a speed of approximately $\frac{1}{5}$ mile per second. At this rate a perceptible echo can be heard at a reasonably small distance, and is measured at a few milliseconds. But after sound is converted to an electrical current, as in the musical instrument amplifier, it is travelling at almost the speed of light. This is approximately 186,000 miles per second, about 930,000 times faster than sound. To achieve even a few milliseconds of delay, an enormous amount of electronic circuitry is required. It is more efficient to convert the electrical currents back into a slower medium. The most common procedure is mechan-

ical, by the use of vibrating coiled springs; or magnetic, by the use of loops of magnetic tape. The use of vibrating coiled springs is the oldest and most common form of electronic reverberation for musical instruments, having been patented in the '30s for the Hammond organ.

An entirely different means of reverberation, not yet in general use but likely to have a large future, is achieved by digital computer techniques. When sound vibrations are converted into analogous electric currents to be amplified and modified, it is an analog electronic process. By converting sounds into digital electronic form, it is possible to achieve time delays at considerably less expense than with analog electronics. Many electronic components are still required, but the state-of-the-art of digital electronic miniaturization by means of integrated circuits is much further developed because of its application in digital computers. As of the early '70s the expense is still not small enough to justify replacing vibrating coiled springs or tape loops in musical instrument amplifiers. But the demand for digital electronic time-delay equipment is enormous in many fields, and should stimulate the mass production of integrated circuitry that can be efficiently employed in music. Digital electronic circuitry for music has many uses beyond reverberation. It has already been experimentally applied to vibrato and equalization, and offers sound modification possibilities without precedent in analog electronic technology. It is a fairly safe prediction that digital electronics for live-electronic music will be a major development in the coming years.

With electronic control of volume, tone, tremolo, and reverberation—not to mention the musical instrument itself—the musician has become a very busy performer. All these means of control pose a human-engineering problem. Some of the electronic controls of the electric guitar are mounted directly on the instrument and some are on the musical instrument amplifier. Since the performer has only two hands, it has proven feasible to construct foot-operated switches and pedals. Furthermore, as new electronic music circuits are developed, it is often more efficient to use them as accessories rather than to build them into the already crowded musical instrument amplifier. Some of the accessory circuits are small enough to be built into the foot controls. The most common example is the "fuzz-tone," which is widely used with the electric guitar and bass. Technically quite simple, the fuzz-tone adds overtones to the original instrumental sound. These overtones are multiples of the original pitch and produce the effect of a cutting edge to the sound. Some fuzz-tone circuits include a treble boost, an extreme emphasis of the high frequencies. Generally the performer has one control of fuzz tone: to switch it on or off. Another example of foot-control is the "wah-wah." This is an application of equalization, a kind of tone-control circuit that sweeps a special filter through the amplified sound. The sweep of some wah-wah circuits can be controlled electronically as well as by the motion of the performer's foot. The electronically controlled wah-wah is varied periodically, much as is the tremolo, though sometimes at rates below one sweep per second.

A group of accessory circuits has been developed to modify the "amplitude-envelope" of musical instruments. Common among these is the "sustain,"

which is used mainly for the electric guitar and bass. The amplitude-envelope might be called the loudness-shape of these instruments. Similar to that of the piano, the amplitude-envelope of these electric instruments is characteristically very loud at the beginning, falls rapidly in loudness to some intermediate level, and then more gradually diminishes to inaudibility. The "sustain" is an automatic gain control, an electronically controlled amplifier. It is normally set at some intermediate level of amplification. When the extremely loud beginning of the guitar sound reaches the input of the sustain, the circuit automatically decreases its level of amplification, then increases it following the inverse of the guitar amplitude-envelope. The audible effect is much like the sustained sound of an electric organ. In its simplest form the performer has a single control of sustain, an on-off switch. Some sustain devices allow the performer to control aspects of the shape of the inverse amplitude-envelope.

Another accessory device called a "phaser" is quite subtle in its effect, and sometimes requires a stereo amplifier with two loudspeakers. The "phaser" achieves a change of phase. Phase change is a special application of time delay, but over a much shorter length of time. It is measured in degrees of a particular wavelength (rather than milliseconds, as in reverberation) and therefore depends on the frequency of the original sound. It is interesting that, psychoacoustically, we do not hear any difference in a sound that is shifted a fixed number of degrees in phase from itself. But we do hear an effect while the sound is being shifted. For example, if the sound stays at 0 degrees in one loudspeaker and changes gradually to 180 degrees in another loudspeaker, the effect is like a movement of that sound. But the listener is hard pressed to determine "what moved where." The effect seems to occur in the listener's head rather than in the performance space. The performer may have several controls for the phaser, including an on-off switch, a control for the number of degrees of shift, and a rate control for applying a periodic electronic phase shift. Phase changes are employed commonly in the studio processing of rock music recordings, where they are sometimes called "phasing" or "flanging." Under carefully controlled studio conditions, some incredible phasing effects have been achieved in stereophonic recordings.

Equalization, tremolo, reverberation, fuzz-tone, wah-wah, sustain, and phasing have been most widely used with the electric organ, guitar, and bass. They have been applied to amplified brass and woodwind instruments as well, but not as frequently. This is as much because of cultural reasons as of artistic traditions. Brass and woodwind instruments are not common in rock or country-western ensembles. As the country-western bands have gradually admitted electric guitars, they have occasionally amplified the violin. But the violin, woodwinds, and brass instruments carry the weight of classical European traditions much more heavily than the electric organ, guitar, or bass. Also, the performers of the traditional instruments have tended to be more conservative, except for a few pioneers in modern jazz and specialists in "serious" experimental music. Furthermore, innovation by the manufacturers of conventional instruments has not exactly been rampant. Electronic innovations notwithstanding, it is remarkable how little innovation in the use of

plastics and special metals has occurred until very recently. Ornette Coleman's first use of a plastic saxophone was a scandal to traditional musicians. Plastic heads for drums were more easily accommodated because the artistic conservatism was outweighed by the practicality of marching bands being able to use such drums in the rain.

There are other cultural differences to consider. Electric guitarists, for example, tend to be young musicians in a culture premised on innovation, and in which originality is commercially viable. Modern jazz is an innovative culture, but, tragically, has achieved little commercial viability in the United States. Only an extremely well-established jazz figure such as Miles Davis is able to make electronic experimentation a commercial proposition. Classically trained musicians spend their formative years learning mostly old traditions, and whatever experimental inclinations existed in their youth tend to be severely repressed.

Except for the development of the electric piano, used mostly in rock and pop ensembles, the conventional mechanical piano has not seen a single important change in more than half a century. Only one major piano manufacturer, Baldwin, has done any fundamental research in acoustics and electronics. For many years this company has done sustained and important work, including the development of an electronic grand piano. The electric piano used in rock ensembles doesn't sound much like a piano and, like the electric guitar, is really a new instrument. Its prime advantages are that it is small and light enough to be portable, and that because of amplification it can match the loudness of the rock ensemble. Compact electric pianos have recently been installed in the lounge sections of transcontinental jetliners.

There is an exception to this conservatism with respect to woodwind and brass instruments. Several manufacturers have marketed an electronic device that enables the musician to add lower octaves to his sound. Technically, the device is a frequency divider, and is a relatively simple application of digital technology to analog electronics. A microphone is attached to the woodwind or brass instrument. Most often it is a miniature microphone that is attached to a modified mouthpiece in order to minimize the possibility of acoustic feedback. The commercial dividers are extremely compact, and are designed to be worn—attached to the clothing—by the musician. The specific details of the circuitry differ from one manufacturer to another, but the important similarity among all such devices is that the produced sounds of the lower octaves are purely electronic, and follow exactly the pitches performed by the woodwind or brass player.

Briefly, the instrumental sound is converted by the microphone to an electrical current, then modified from its original shape to a square wave of the same fundamental frequency as the instrumental pitch. This square wave is then applied to a divider circuit, several types of which are in use. A particularly reliable circuit called a "flip-flop" is widely used in digital computers and some types of electric organs. The output of the flip-flop is also a squarewave, but at exactly one-half the frequency of the input. One-half of any frequency is the next lower octave. To obtain the second lower octave, the output

of the flip-flop is applied to a second flip-flop. This produces a division of the original instrumental pitch by four. Three flip-flops in a row will provide a third lower octave—a division by eight of the original instrumental pitch—and so on. Commercial dividers use, at most, three divider circuits. The outputs of each divider are available in parallel, so that by means of switches, the performer can choose any one or any combination of lower circuits. Finally, some lower-octave circuits include electronic filtering to shape the square-wave outputs so that they sound more like an acoustic instrumental sound. Because the musician varies his loudness when playing, automatic amplitude circuitry is sometimes included so that the dividers will function properly over a wide dynamic range. Except for more elaborate custom-built dividers—which can include division to intervals other than octave sub-multiples, and which will automatically produce an output amplitude proportional to the instrumentalist's dynamics—there are definite limitations on the commercial lower-octave accessories for woodwind and brass instruments. All of the above-mentioned electronic procedures have one feature in common: the pitch integrity of the original sound is preserved. Only amplitude, timbre, and time relationships are altered. Pitch relationships are changed only by divider circuits, and then only by exact sub-multiples that preserve traditional pitch relationships.

Performers of live-electronic music have also made use of circuits that modify pitch relationships, but mostly in the realm of "serious" experimental music. Modification of pitch relationships beyond the domain of the chromatic scale still presents the world of commercial music—even the most extreme innovators in rock music—with fundamental philosophic problems. These effects have been used in rock, but for incidental color rather than for the potential of their fundamentally new language. The device most often employed for changing pitch relationships is the balanced modulator. This instrument has various forms and names, including the ring modulator and the analog multiplier. In its simplest form it is a circuit with two inputs and one output. The original sound is applied to one input and a control signal is applied to the other input. The output is a multiplication of the two inputs, and depending on the characteristics of the control signal, consists of the arithmetical sums and differences of the two inputs. Considerable variation of the simple form of the circuit is possible. The sum and difference frequencies can be combined with the original sound, and the circuit can be unbalanced in various degrees. The control signal can derive from or depend upon the original sound or other instrumental pitches. At least one commercial accessory device of the balanced-modulator type, designed by Thomas Oberheim, has been marketed for live-performance electronic music, and several mini-synthesizers include this function.

Many complex circuit configurations of analog multipliers are possible. These enable the choice of either sum or difference frequencies, multiple multiplication with control signals in the radio-frequency spectrum, precise control of complex pitch relationships using parametric amplification, and other elaborate procedures. Besides the deterrent effect of musical conservatism, experimentation with these procedures has been limited by the relatively high

cost of equipment. Integrated circuit technology is gradually reducing the cost to reasonable amounts.

Another live-performance electronic accessory, which is considerably more complicated, is the percussion generator. Known by names such as "sideman" and "bandbox," and historically related to the automated mechanical percussion of the nickelodeon, these accessories electronically synthesize sounds resembling the bass drum, tom-toms, bongos, woodblocks, cymbals, and the like. The performer has a choice of specific rhythms and tempi, which are also electronically generated. The percussion generator is commonly used as an accessory to the electric organ.

There are also several keyboard-operated electronic accessories for playing melodies with various timbres and inflections; these usually imitate traditional melodic instruments. One of the earliest, the Solovox, is often attached to the traditional piano. Recently the synthesizer firm of Tonus, Inc. introduced a keyboard-operated electronic melody-maker called the ARP Soloist, which updates the Solovox with numerous innovations, including portamento and diverse envelope and timbre control. More complicated are the mini-synthesizers. Though essentially able to produce only solo melodic lines, these instruments can be tuned to produce nontraditional scales. More significantly, the design premise of most mini-synthesizers is that they are live-performance instruments of electronic sound, not attempts to imitate acoustic instruments. At least one electric organ includes accessory functions that enable the performer to imitate the electronic sounds of the recently popular "switched-on" synthesized music!

The Chamberlain is probably the most unusual live-performance invention. It consists of a series of magnetic tape loops, with each loop actuated by a corresponding key on a traditional keyboard. The sounds to be heard from the Chamberlain can be from any source, and are recorded by the performer in advance. A dramatic example of the use of the Chamberlain is the introduction to Ramon Sender's *Desert Ambulance* (1964).

The skills applied by live performers with all these devices are evident not only in how they are used in a musical context, but also in how they are used in combination with one another. These many combinations represent the most promise for the further development of the musical capabilities of these accessories.

Extensions of Electronic Technology in various Live-Performance Arts

Throughout history creative artists have tinkered with technology and dabbled with multi-media. Da Vinci and Wagner are immediate examples. In the twentieth century the rapid increase of social mobility, technological affluence, and artistic innovation and communication have given the creative artist an irresistible access to multiple fields of endeavor. It is increasingly difficult to fit artists into traditional categories. It is no longer surprising to find that esteemed musicians invented the air brake, color photography film, and insur-

ance actuarial procedures, nor that they hold patents in electronic design and in dye processes for synthetic fibers. It is not unusual to find people still in their early twenties who present their musical work in concert one week, and their papers in computer-science conferences or their films at international festivals the week after. What is to be said of a figure like John Cage, who is known to some as a composer, to others as a mycologist, a poet, or a graphic artist, or to still others as an influential writer on social and economic issues?

With few exceptions, the technological resources that have nourished multi-media performance are electronic in origin. This electronic feasibility is due to developments in solid-state physics ranging from the transistor to integrated circuitry. It is electronic *control*, of increasing complexity with decreasing cost, that has become artistically feasible. The logistics of multi-media production can be formidable, and may account for why multi-media projects are often collaborative efforts. But multi-media artists may also collaborate because they enjoy working on fundamental creative levels. Increasingly, they share the languages of various media, particularly the near-universal language of electronic technology.

Besides the new sources of sound, electronic control of audio has made possible entirely new ensemble forms, from musically interactive man-machine systems to complete automation. Applications of electronic control to video technology have expanded this medium from cinema to television, video recording, and laser projection. Electronic video control can be as simple as the synchronization of slide projectors, or as complex as the translation of sound into laser-projected images or the computer synthesis of color-television images. Finally, electronic control has given the artist a means of interrelating different media that in the past has been vastly too complicated to consider.

Sound Sculpture

Between the realms of live-electronic music and multi-media is the world of sound-producing sculpture. By slightly broadening this category, the earliest activities of this nature could include the electrically powered mechanical instruments of Luigi Russolo and the Milano Futuristi after the First World War and the incredible *Studies for Player Piano* composed in Mexico by Conlon Nancarrow. Between the Second World War and 1960 the first notable activities in sound-producing sculpture were those of Mauricio Kagel in Argentina, Jean Tinguely and the collaboration of Pierre Henry and Nicolas Schöffer in France, and Joe Jones in the United States. In 1953 Kagel made a sound and light score for a 120-foot tower of César Janello. Tinguely's mechanical sculptures of the '50s produced their own vigorous sounds without the aid of electronic amplification. In 1955 Pierre Henry made music for a 150-foot "cybernetic tower" by Nicolas Schöffer. Beginning in the late '50s, New York artist Joe Jones produced a veritable menagerie of ebullient sculptural soundmakers, which were electrically powered and controlled by switches, photocells, and various sensors.

After 1960, artists from many countries produced sound-sculpture. These

include Belgium (Henri Pousseur), Canada (François Dallegret, Pierre Mercure), England (Roberto Gerhard, Daphne Oram), France (Takis, Marcel van Thienen), Japan (Kuniharu Akiyama, Toshi Ichiyanagi), the Netherlands (Peter Schat), Spain (Mestres Quadreny), Sweden (Öyvind Fahlström and Per-Olav Strömberg), and the United States (Milton Cohen, Walter De Maria and Le Monte Young, Robert Rauschenberg, James Seawright). The diversity of solid-state control devices that appeared during the '60s was a considerable stimulus to these creative artists of sound- and light-sculpture. The surge of activity in the kinetic sculpture of artists such as Seawright, and the programmed light performances of artists such as Cohen and Anthony Martin was nourished as well with by-products of the digital computer industry, including integrated logic-circuitry. The international phenomenon of the rock light-show discotheque followed closely the work of these artists.

A particularly interesting example of sound sculpture is the *Moosack Machine* of California composer Stanley Lunetta. The *Moosack Machine* produces, mixes, and processes sound and light activities completely on its own. Considering the interaction among its many elements, the probability of its repeating itself, even after many hours of continuous performance, seems incredibly small. The sounds of the *Moosack Machine* are produced by oscillators, the frequency and amplitude of which are controlled by a combination of light, temperature, and proximity sensors. The resultant sounds are mixed, modified, and articulated in conjunction with a logic system consisting of a 16-bit digital counter/decoder and a frequency-divider chain. Various moving parts, a transducer, and the lighting of the sculpture are also activated by the digital logic system. The motion, lighting, and temperature of the *Moosack Machine* and its environment are monitored by the same sensors that control the initial sound generation, thus completing the complex feedback loop of this self-sustained sculpture system. The design and character of the *Moosack Machine* is such that it is on that nebulous line between an automaton and an artificial intelligence. In this sense it is a candidate for the category of live-electronic music because it so closely mimics the attributes of live performance.

The "instrumental loudspeakers" of David Tudor's *Rainforest* (mentioned previously) also fit the category of sound sculpture. Many of the resonating materials are literally "found objects." Further, the sounds of *Rainforest* are very dependent upon the space in which they are heard. This use of the acoustical space as a significant factor in the electronic processing of the work suggests an extension of the category of "sound sculpture" to include "sound environment." Several other works belong here, including Pauline Oliveros' *In Memoriam Nicola Tesla, Cosmic Engineer* (1968), Alvin Lucier's *I am sitting in a room* (1970), and my own *Hornpipe* (1967).

Oliveros' *In Memoriam Nicola Tesla, Cosmic Engineer* was commissioned by the Merce Cunningham Dance Co. and has been widely performed with the evening-long dance *Canfield*. In her work Oliveros has the performers conduct an acoustical analysis of the performance space. For the closing section the space is subjected to a sea of low-frequency sounds which establish physically imposing standing waves and structural resonances in the building

itself. Lucier's *I am sitting in a room* treats the natural resonances of the performance space as an acoustical filter. A spoken text is recorded, then immediately played back into the same space. That playback itself is recorded, and the second recording played back into the space. The process continues until the verbal intelligibility of the text has disappeared in the mysteriously abstracted resonances of the original speech rhythms. In my own work *Hornpipe* a solo hornist wears on his belt an electronic circuitry which analyzes the resonances of the space. This analysis is accomplished by a series of tunable, gated amplifiers which adjust their own resonances to complement those of the performance space. When sufficient resonance information has been gathered by each gated amplifier, the gate opens and the resonance of that particular amplifier is heard from loudspeakers. In the course of the performance the hornist learns the constellation of resonances for that particular space, and is able to deactivate the electronic circuitry by playing sounds which are out of the resonant constellation. Since the resonances are activated by the sounds which the hornist plays, both the electronic circuitry and the acoustical space are part of the ensemble of the work.

Television and Video Recording

Video technology—the translation of images into electrical and magnetic form for transmission, modification, and recording—requires considerably more sophisticated equipment than is usually encountered in audio technology. Compared to audio, the frequency spectrum (or bandwidth) of video is much wider (as much as 6 MHz) and requires the use of radio-frequency electronics. Video recording on magnetic tape, which has given creative artists access to television—much as magnetic audio recording made electronic music generally accessible—is quite different from audio recording, in which the magnetic translation of sound vibrations are recorded by a stationary recording head along the length of a moving magnetic tape. In video recording each image is scanned several hundred times, and each scan is recorded by a rotating recording head diagonally across the width of a moving magnetic tape. This complexity is necessary to achieve the greater bandwidth required for television signals. Besides having a head for the television signals, videotape has at least two other tracks: one for the audio signals and one for synchronizing signals. There are some similarities between video and audio recording. The camera is analogous to the microphone, the amplifiers are virtually the same except for differences in bandwidth and equalization, the recorders use magnetic tape that is stored on reels or cassettes, and the television screen is analogous to the loudspeaker. As with audio, video signals can be mixed, filtered, edited, and even "reverberated," though the specific equipment for these functions is different. The intensity of a video image is controlled in the same way as the amplitude of an audio signal. Of particular relevance to the creative artist is the fact that video images, like audio signals, can be electronically synthesized.

One of the most interesting aspects of video technology is the control of color. Though even more complicated than monochrome television, color has

keying is enormous, and the technique can be used for dramatic abstracting of images. It is curious that "audio-keying," which is analogous to video-keying, is also possible but has been used in very few electronic-music works. However, audio signals are commonly used to synthesize and modify television images.

Beginning in 1965 Lowell Cross composed a series of works in which television images were produced by audio deflection and modulation of the electron beam. One of the most interesting is *Musica Instrumentalis,* for color television, which is performed live by David Tudor on a stereophonic bandoneon. The score consists of color images that Tudor, by performing the bandoneon, attempts to reproduce on the television screen. Steven Beck has designed a live-performance electronic image synthesizer that uses both audio and video signals, and has produced several real-time video tapes in collaboration with composer Richard Felciano. Woody and Steina Vasulka perform live with a color synthesizer, which they often use with synthesized images from monochrome videotape, exploring the beautiful realm of color that lies just above the threshold of color perception.

The size of the television screen is limited by the practicalities of cathode-ray tube manufacture, and the general use of solid-state flat-screen developments is still some years in the future. Projection television has been used to fill large areas with image, though except for the Eidophor projection system, the image intensity has been less than satisfactory. To date, then, television has been an artistic medium of chamber-music scale.

Lasers

The electronic manipulation of images in large spaces first became practical in the '60s with the development of the laser. The laser is fundamentally different from any previous light-generating procedure in that it produces a beam of light that is coherent: the light energy is predominantly a single frequency. The laser most commonly used by artists—because of its low cost—is the helium-neon gas laser, which emits a deep red light beam of 6,328 Angstroms. The visible spectrum of light is roughly between 3,800 and 7,600 Angstroms. Lasers can be made with other gases, as well as with fluorides, tungstates, metallic oxides, and various semiconductors, to produce visible coherent light of other colors. The laser can be manipulated in two basic ways: beam deflection and intensity modulation. Beam deflection is accomplished in several ways; the most practical seems to be with a mirror-galvanometer, an electro-optical device in which a small mirror moves according to audio-frequency signals. If two mirror-galvanometers are used, one for the vertical axis and the other for the horizontal, the laser beam projects oscillographic images. Intensity modulation can be achieved by light-polarizing semiconductors.

Among the projects of artists who have used lasers in live performance, one of the most interesting was the *Video/Laser I,* a collaboration of Lowell Cross, Carson Jeffries, and David Tudor, developed for the Pepsi-Cola Pavilion at EXPO 70 in Osaka. For *Video/Laser I* a Krypton-ion laser that generated four colors (red, yellow, green, and blue) simultaneously was used. By modulat-

ing each of the four beams separately and by projecting them through various translucent materials, complex kinetic diffraction patterns were produced.

In Paris in October, 1972 the composer Iannis Xenakis, who had worked with Edgard Varèse and the architect Le Corbusier on the Philips Pavilion at Brussels in the late '50s, presented a stochastically determined light and sound spectacle called Polytope de Cluny. By means of program-control tapes, Xenakis synchronized musique concrète with a four-color matrix of rapidly articulated lasers and a constellation of several hundred strobe lights.

Artistic applications of holography, a three-dimensional image process that requires laser light, are just beginning. Present technology limits the viewing aperture of holographic images to approximately twelve square inches. Similarly small in area (as of the early '70s), other means of electro-visual display, such as light-emitting diodes and liquid crystals, are already being used in small calculators and digital time pieces. Along with holography, these phenomena hold fantastic possibilities for the visual arts of the future.

Astro-bio-geo-physical Application

With the development of ultra-sensitive electronic equipment during the past half century, much previously unknown astrophysical, biophysical, and geophysical activity has been detected. Geophysical activity had been experienced in the physical manifestations of tides, earthquakes, and tsunamis. But the accurate measurement of this activity, as well as of the formerly undetected microseisms, gravity waves, long-period resonance, and seismic propagation characteristics of the earth, were possible only with the development of low-noise, high-gain amplification and electronic transducers. Astrophysical activity was obvious from the visible light spectrum, but the greatest part of this activity—such as electromagnetic and cosmic radiation—was not revealed until the advent of specialized magnetic sensors, radio astronomy, and interplanetary exploration. Biophysical electrical activity became important with the use of sophisticated electronics in physiological and medical research.

In the '60s several composers began using these phenomena in their works, mostly for live-electronic music. The explorations of Alvin Lucier have been remarkable for their musical implications as well as their conceptual diversity. Lucier's *Music for Solo Performer 1965,* perhaps the earliest use of electroencephalic signals in live musical performance, amplifies the brainwave alpha currents of a solo performer. With practice, the performer learns to turn his alpha current on or off at will. Seated on stage, with electrodes attached to the occipital lobes of his head and to a neurological amplifier, the performer articulates with his alpha currents the sympathetic resonances of an ensemble of percussion instruments.

In December, 1970 composer David Rosenboom presented his *Ecology of the Skin,* in which the alpha, beta, and theta currents of several people were applied to control inputs of an electronic-music synthesizer. Not only were sounds heard from this synthesizer, but members of the audience could have their own private light show by applying phogene-stimulating electrodes to

their temporal lobes. At the same time, in his *Corticalart* production at the Modern Art Museum of Paris, Pierre Henry wired his head into a sprawling arrangement of apparatus that purportedly modulated the color of a television set as well as producing sound.

In 1966 Alvin Lucier composed *Whistlers,* in which, with special VLF radios, the sounds of electromagnetic disturbances were received from the ionosphere and electronically processed by an ensemble of live performers. Later that year, at the 9 Evenings of Theater and Engineering in New York City, John Cage presented his *Variations VII,* the sounds of which were obtained live from wired and wireless communications sources. Also on the 9 Evenings performances, Lucinda Childs presented her *Vehicle,* a work using doppler sonar; Alex Hay presented his *Grass Field,* a work using amplified brain waves and muscle movements; and David Tudor presented his *Bandoneon!,* a "combine" of programmed audio circuits, moving loudspeakers, and instrumentally derived television images.

In 1967 Lucier presented his *Shelter,* in which environmental sound sensing, using the propagation characteristics of walls, floors, and ceilings, was achieved by amplifying the signals from special vibration transducers. This musical seismology makes use of man-made disturbances, though in twentieth-century urban life it is difficult to distinguish between man-made and geophysical microseismic activity. Other musical uses of geophysical phenomena include my own *Mographs* (1962–64), the sounds of which occur in time according to the wave-front arrivals of underground nuclear explosions; and Charles Dodge's *Earth's Magnetic Field* (1970), in which the succession of computer-synthesized sounds corresponds to the kp indexes of the magnetic activity of the Earth for the year 1961.

Lucier's *Vespers* (1968) uses pulsed, high-frequency sound for echo location, much as do (and in honor of) bats and other animal experts in acoustic orientation. In Gerald Shapiro's *The Second Piece* (1971), the audio modulations of infrared light beams are used by the performers for spatial orientation. These two works, along with Lucinda Childs' doppler-sonar *Vehicle,* are special examples of music derived from biophysical sources. They are *surrogate* electronic extensions of human biophysical capabilities, and are often modeled after other animal or artificial systems. One reason why surrogate biophysical systems are attractive is that a specific intention can be accomplished with greater convenience than is the case in directly monitoring a biophysical process. For example, my own piece, *BEAM,* performed in Tokyo in 1969, requires monitoring of the physical motion of the bow arms as well as the sounds of a violinist and violist. Originally, I planned to monitor directly the myoelectrical signals of the performers. These signals are pulses that change in rate according to the contraction and fatigue of the bow-arm muscles; they were to determine both the electronic modification of the instrumental sound and the digital display of the computer-controlled score. Because of the discomfort and unreliability of direct wiring to the muscles, a surrogate system of electronic position sensors was designed in the form of bow-arm sleeves that were com-

fortably worn by the performers. These sleeves generated variable-rate pulses similar to those of the muscles that they covered, and the original intention was fulfilled.

Some biophysical signals are relatively easy to obtain directly. Cardiac and respiratory sounds can be amplified from outside the chest. Pauline Oliveros has used amplified heartbeats in live performances of her *Valentine* (1968), for four card players, and in her ESP-oriented $\int \Psi^* \Psi d\tau = 1$ (The Indefinite Integral of Psi Star Psi d Tau equals One), for heartbeat, Shakuhachi, and an ensemble of singers, actors, and instrumentalists. For the accompaniment to Merce Cunningham's *Loops* (1971), the heart and respiratory sounds of a solo dancer are transmitted by wireless and amplified in live performance.

Multi-Media

Using all sorts of spatial environments, multi-media can involve all the physical senses, and often transforms the audience from spectators to participants. The practice of multi-media is so widespread and is applied to so many performance circumstances that it is imperative here to focus primarily on the ways that *composers* have contributed to the art. Multi-media productions have received special attention at international expositions, particularly those at Brussels in 1958, Montreal in 1967, and Osaka in 1970. The Philips Pavilion at Brussels, in which Varèse's *Poème Electronique* was heard circulating through 425 loudspeakers, and the Pepsi-Cola Pavilion at Osaka, designed by a collaboration of several dozen avant-garde artists, are historic.

In the United States in 1957 (the year of preparation for the Philips Pavilion), the weekly *Vortex* performances at the Morrison Planetarium in San Francisco and the *Manifestations: Light and Sound* performances in Ann Arbor were pioneering events in the intermedia of electronic music and light projection. These performances were collaborations, *Vortex* being directed by Jordan Belson and Henry Jacobs, and *Manifestations* by Milton Cohen. In the following decade, at approximately three-year intervals, new multi-media collaborations were formed. 1960 saw the formation of the San Francisco Tape Music Center (Pauline Oliveros, Ramon Sender, Morton Subotnick, Terry Riley) and the activities of Tokyo's Group Ongaku and Sogetsu Art Center (Kuniharu Akiyama, Toshi Ichiyanagi, Joji Yuasa, Takahisa Kosugi, Chieko Shiomi, and others). 1963 was the beginning of the Los Angeles Experimental Music Workshop (composer Joseph Byrd and others), La Monte Young's Theatre of Eternal Music in New York, and, in Ann Arbor, the Space Theatre and the ONCE Group. 1966 witnessed the organization of USCO in New York (Gerd Stern, Stan Van Der Beek, Jud Yalkut, and others), Pulsa in New Haven, and the multi-media performances directed by Udo Kasemets at the Isaacs Gallery in Toronto. Throughout this decade parallel developments were occurring in theater, happenings, modern dance, and cinema. At the University of Illinois during the '60s, John Cage was involved in two multi-media extravaganzas. His *Music Circus* involved several hundred performers in a livestock

pavilion. *HPSCHD,* a collaboration with Lejaren Hiller, Ronald Nameth, and a computer, was a five-hour performance with seven harpsichords and hundreds of tape recorders and projectors.

The beginnings of multi-media in South America were apparent after 1964 in the experimental music centers of Buenos Aires (at the Instituto Torcuato de Tella) and in Cordoba. In 1967 Jose Vicente Asuar composed his two-hour *Homenaje a Caracas* for four tracks of tape, thirty-eight projectors, fifty live performers, and a large metal structure. The Brazilian Jocy de Oliveira introduced her *Probabilistic Theatre I* in 1967, and her *Polinteracoes* in St. Louis in 1970.

The most remarkable of all multi-media collaborations was probably the Pepsi-Cola Pavilion for Expo 70 in Osaka. This project included many ideas distilled from previous multi-media activities, and significantly advanced both the art and technology by numerous innovations. The Expo 70 pavilion was remarkable for several reasons. It was an international collaboration of dozens of artists, as many engineers, and numerous industries, all coordinated by Experiments in Art and Technology, Inc. From several hundred proposals, the projects of twenty-eight artists and musicians were selected for presentation in the pavilion. The outside of the pavilion was a 120-foot-diameter geodesic dome of white plastic and steel, enshrouded by an ever-changing, artificially generated water-vapor cloud. The public plaza in front of the pavilion contained seven man-sized, sound-emitting floats, that moved slowly and changed direction when touched. A thirty-foot polar heliostat sculpture tracked the sun and reflected a ten-foot-diameter sunbeam from its elliptical mirror through the cloud onto the pavilion. The inside of the pavilion consisted of two large spaces, one black-walled and clam-shaped, the other a ninety-foot high hemispherical mirror dome. The sound and light environment of these spaces was achieved by an innovative audio and optical system consisting of state-of-the-art analog audio circuitry, with krypton-laser, tungston, quartz-iodide, and xenon lighting, all controlled by a specially designed digital computer programming facility.

The sound, light, and control systems, and their integration with the unique hemispherical acoustics and optics of the pavilion, were controlled from a movable console. On this console the lighting and sound had separate panels from which the intensities, colors, and directions of the lighting, pitches, loudness, timbre, and directions of the sound could be controlled by live performers. The sound-moving capabilities of the dome were achieved with a rhombic grid of thirty-seven loudspeakers surrounding the dome, and were designed to allow the movement of sounds from point, straight line, curved, and field types of sources. The speed of movement could vary from extremely slow to fast enough to lose the sense of motion. The sounds to be heard could be from any live, taped, or synthesized source, and up to thirty-two different inputs could be controlled at one time. Furthermore, it was possible to electronically modify these inputs by using eight channels of modification circuitry that could change the pitch, loudness, and timbre in a vast number of combinations. Another console panel contained digital circuitry that could be pro-

grammed to automatically control aspects of the light and sound. By their programming of this control panel, the performers could delegate any amount of the light and sound functions to the digital circuitry. Thus, at one extreme the pavilion could be entirely a live-performance instrument, and at the other, an automated environment. The most important design concept of the pavilion was that it was a live-performance, multi-media instrument. Between the extremes of manual and automatic control of so many aspects of environment, the artist could establish all sorts of sophisticated man-machine performance interactions.

As electronic technology continues to diversify, and as more physical phenomena become accessible, creative artists are likely to increase their exploration of new ways of relating human and other natural systems to artificial systems, for use in the live-performance arts.