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DEMYSTIFYING AND CLASSIFYING
ELECTRONIC MUSIC INSTRUMENTS

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Ethnomusicologists expressly intend to encompass a domain of scholarly investigation including all the world’s music. Therefore, we must confront and address an ever-widening phenomenon that has had an extraordinary impact on music in the 20th century—music electronics. This phenomenon is no longer limited to the United States or Western Europe, but has become world-wide. The specific timbres and accurately repeated rhythmic patterns of electronic music can be heard almost everywhere: in concerts, ceremonial occasions, homes, and in urban as well as rural regions. Music electronics have now become an important subject which focuses on contemporary social and cultural phenomena in music. Since we accept Charles Seeger's concept that ethno-musicology is the study of all music in its cultural context, it follows that there should be expanded classification schemes to incorporate all music instruments.

The use of electronic music technology in non-Western cultures is increasing throughout the world; its further spread is inevitable. No matter where ethnomusicologists choose to study, eventually we will be faced with this technology. Rather than assuming that “the gods must be crazy” for providing it, let us assume instead that this technology is merely another step in the ongoing process of development in musics of the world. As a valid part of culture which affects music, music electronics become a valid part of our research and represent the fundamental issues of the processes of change, adaptation, and acculturation.

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To date, there has been limited discussion on the subject of how the use of electronic music instruments and related technologies has affected and transformed the way music is made and perceived worldwide. There are a number of probable reasons for this lack of attention. First, electronic music technology, through its intimate connection with Euro-American commercial music, is apparently seen by many of us, either consciously or subconsciously, as a largely negative force. Electronic music technology is an integral component of mass-market commercial music, the impetus for a perceived "cultural grey-out" (Nettl 1983:345-7) resulting from worldwide homogenization of indigenous musical traditions.

At a theoretical level, modern ethnomusicology advocates the study of musical change resulting from the effects of modernization and Westernization. In practice, however, there still seems to be an inherent ideal of musical purity which attracts us to so-called "traditional" aspects of the musics. Electronic music is not necessarily considered the traditional music of any culture, except, perhaps, that of American and Western European youth and the "nether regions of avant-garde experimentalism" (Bakan 1988:1). Contributing to this attitude toward music electronics is the historical background of the field of ethnomusicology itself. Ethnomusicology began with the study of non-Western music cultures. Recently Western popular musics have gained limited acceptance as appropriate subject matter for ethnomusicological attention (e.g., Bakan 1988), but there still remains resistance within the scholarly community.

The study of music electronics offers many new avenues for future research. Music electronics could well be the common denominator for comparative study. As this technology gains acceptance and broader usage in various cultures, the traditional musical elements that are retained and emphasized could give insight as to which elements are most important to that culture. This retention and emphasis would be an emic representation of cultural musical aesthetics and would provide a basis for cross-cultural comparative studies of musical elements, aesthetics, adaptation, and acculturation. Through their increasing worldwide popularity, electronic music instruments provide a convenient method for obtaining deeper understanding of music traditions from a cross-cultural perspective. Ethnomusicologists have long been trying to investigate common features of different musical traditions through comparative methodology. Such attempts, however, are easily frustrated. Often there is a lack of in-depth knowledge of a variety of traditions which makes valid comparisons impossible. Electronic music instruments, however, may properly fill the need for a valid common denominator. Through cross-cultural study of the use of electronic music technology and instruments, we may be able to distinguish various commonalities in music styles, aesthetics, and personal preferences of different cultures as the same electronic music instruments are commonly adopted. Similarities may become apparent; from a broader point of view, it may
also help improve our understanding of the stable aspects of music culture as well as variables cross-culturally.

A major element in the resistance to the study of electronic music could be the abundance of technical terminology. One glance at any publication dealing with the subject of electronic music, even popular journals such as *Keyboard* or *Music Technology*, is apt to turn up terms such as piezoelectric crystal pickups, status bytes, or kilobauds. However, the initial panic caused by this technical terminology is merely a reincarnation of the unease with which we first viewed terms like poly-heterochord musical bow or partly stopped flute with external duct. How many of us, upon first hearing the now commonplace term *mbira* (a plucked idiophone with laced-on lamellae, with or without a resonator), could visualize the instrument, know the sounds it was capable of producing, or how to produce those sounds? Jargon is a problem. Indeed, the sense of futility in coming to terms with the abundance of electronically oriented jargon is further aggravated by the rapid increase in the technology itself, which in turn fosters more and more jargon.

In this paper, we suggest an easy-to-use and flexible classification system of electronic music instruments and related technologies, using the already familiar format set forth by Erich von Hornbostel and Curt Sachs (1914). Our system illustrates various types of electronic music instruments and their relations to one another, as well as a brief definition of some of the more common terms.

As early as the 8th century B.C., various systems had been proposed to categorize or describe music instruments logically. These systems have ranged from the relatively simple (e.g., the ancient Chinese categories based on sounding materials of metal, stone, silk, bamboo, gourd, clay, skin, and wood) to the complex (e.g., Hood’s organograms [1971:144-196], and Heyde’s graphic flow chart system [1975]). By far the most prevalent system in use today is that proposed by Hornbostel and Sachs in 1914, which was based on Mahillon’s interpretation of an Indian instrument classification system (see Jairazbhoy, pp. 67-72, in this volume). Based on the principles of sound production, the Hornbostel-Sachs system utilizes four main categories: idiophones, membranophones, chordophones, and aerophones.

Hornbostel and Sachs felt that flexibility was the crucial factor in determining the validity of any system: Are its criteria inclusive enough and flexible enough to incorporate new discoveries and inventions? When first proposed in 1914, the Hornbostel-Sachs system appeared broad enough to incorporate virtually any instrument in the world within one of its over 300 entries, or in any easily created subdivision. Recently, the Hornbostel-Sachs system has been expanded for further clarification of existing instruments (Bryant 1989) and modified to accommodate newly created instruments (Takanuma 1989). As more instruments are coming to light through ethnomusicological research, we are continually realizing that the system, as first conceived, has limitations.
In the seventy-five years since Hornbostel and Sachs presented their system, rapidly developing technology has produced music instruments which do not fit logically into any one of the four major categories; namely, electric and electronic music instruments. The general remedy for this situation has been to tack on an amorphous fifth category termed "electrophones" (perhaps first coined by Sachs 1940:448). Any instruments which are associated in any way with electricity have been lumped together in what amounts to a "miscellaneous" category, in Hornbostel's and Sachs' own words, "an admission of defeat" (1914, trans. 1961:6). Within this category of electrophones, one often finds instruments such as the electric guitar, the electric organ, and various types of synthesizers in illogical juxtaposition; illogical because their methods of sound production vary greatly, thus defeating the aim of the system. We can no longer limit our organological thinking to the four original Hornbostel and Sachs categories. Electronic instruments fit none of these categories and should not be relegated to a miscellaneous category, nor mentioned as an aside.

The system proposed here can be considered to be cross-cultural, endogenous, and delimited, as explicated by DeVale in her introductory article to this volume, "Organizing Organology." It is cross-cultural in that its taxonomic criteria have worldwide applicability; electronic music instruments from any culture will fit into its categories. The system is also endogenous; it has been devised by culture members and users of the instruments. The system is delimited to electronic instruments. This is a modular system: through the use of plus signs (+) any configuration of electronic music equipment can be classified.

Our original intention for this project was to elaborate upon the category of electrophones. The more research we did, however, the more we came to realize that this one category was proving inadequate for the needs of the instruments involved. If we were to follow the original aim of system, classifying instruments according to methods of sound production, we could not include electric guitars and synthesizers in the same category, since their methods of sound production differ radically. We have resolved this difficulty by adopting Mantle Hood's term "electronophones" (1971:144) for the fifth category to be added to the Hornbostel-Sachs system. This category now includes only those instruments which produce sound by purely electronic means. Instruments such as the electric guitar remain in their original Hornbostel-Sachs category (in this case, as a chordophone), but are now distinguished through the use of suffixes which denote if the instruments are amplified or electric.

There still remained the dilemma of how to classify items such as sequencers and sound processors, instruments which do not directly produce sound but whose application drastically alters the way in which the tones finally are heard. Strictly speaking, they cannot be placed within the Hornbostel-Sachs classification system, since they are not sound-producing instruments. However, within the culture, they are considered by users to be an essential part of the music creating process. We feel that one solution may be to view this process as a system of
performer-instrument-modifiers-acoustic space-receiver (Lieberman, personal communication, 1989). Following this approach, devices such as sequencers and sound processors would fall within the domain of modifiers, which will be given a separate classification scheme. The entire system can be found in Appendices A and B in outline and graph forms.

Before detailing the category of electronophones, it is first necessary to distinguish between those instruments which we consider to be electronophones (in accordance with the parameters of the category), and those which have previously been indiscriminately lumped together under the rubric electronophones.

AMPLIFIED AND ELECTRIC INSTRUMENTS

An amplified instrument (for example, an amplified acoustic guitar) is an acoustic instrument whose volume is increased by converting the sound into an electrical signal for playback through a loudspeaker. This conversion is done through the use of a separate device such as a pick-up or a microphone. The term "electric" refers to instruments in which the amplification and sound modifying devices are an integral part of the instrument. These instruments normally do not function independently of the electric devices. The method of sound production for the electric guitar is no different than that of the acoustic guitar; both produce sound as the result of the vibration of strings. The electric guitar, however, cannot stand alone; it must be channeled through an amplification system in order to be heard. In essence, the amplifier functions as would the resonator in an acoustic instrument.

In terms of classifying these instruments within the Hornbostel-Sachs system, we contend that amplified and electric instruments should remain in their categories within the original system, but with the addition of a clarifying suffix: the addition of the letter A (for amplified) or E (for electric) at the end of the classification number. Thus the classification number for the electric guitar would be 321.322-E: necked guitar, electric. The suffixes A and E could be employed with any instrument to which amplification- or timbre-altering electric devices have been added. Other examples include the electric bass, amplified saxophones, and electric violins.

Some instruments are more difficult to classify. For example, the "scratch turntable" used in rap music would best be classified as an electric scraped idiophone. Its classification number would thus be 112.2-E. On a more esoteric note, another problematic example is the use of a cactus plant from which the needles are extracted. The sound of the needles being pulled from the plant is amplified. John Cage has used this in his composition Child of Tree (1975). We suggest that this could be classified either as a amplified plucked idiophone, 123-A, or as an amplified plosive aerophone, 413.1-A.
ANALOG AND DIGITAL PROCESSING

The following explanations will clarify some of the more common terms of electronic music technology which will be encountered in the discussion of the classification system proper: analog, digital, and MIDI.

The primary difference between digital and analog systems is the signal used to transmit and manipulate information. In general, analog systems are better for dealing with the "real" world. Information that comes from natural phenomena is usually continuous, varying throughout a given range. For example, consider the temperature of the room in which you are sitting, the passage of time, or the weight of your body on the chair. Giving a numerical, i.e., digital, value to any of these can only be an approximation of the inherent analog quantity. It is convenient to say that a person might have a weight of 110 pounds, but it would be more accurate to say 110.12333691 pounds. It is obvious that a digital measurement is limited by the degree of resolution of its system. That is why digital systems work better with information that is naturally divided into steps, such as integer numbers (Vaughn 1988:16-19).

In dealing with sound, or its analogous voltage fluctuation, digital signal processing is awkward. The music signal must be checked regularly at a very fast rate, the voltage must be converted to a digital number which is then multiplied, and a new number converted back to an analog voltage which becomes the output. In terms of sound waves in the range of human hearing, it is necessary to take some assessment of the voltage level, which corresponds to the displacement of the medium in a sound wave, at least twice for each cycle. The upper range of human hearing is about 20,000 cycles per second. Therefore, to get any measure of such a period, the sampling rate would have to be at least 40,000 times per second. In recent years a rate of 40,000 to 150,000 samples per second has become feasible, improving the quality of digital recording, playback, and music synthesis.

The main advantage of digital signal processing is that the information may be stored much more easily, and indefinitely, on a magnetic or optical medium. Digital information can also be more accurate because it does not have to manipulate the signal to create an analog version of it. In order to handle information, an analog system has to take an electrical impulse and process it until it matches the information that is to be transmitted as acoustic energy. There is always some error which must be reduced or compensated for in some way. A good example is the number you get for your weight on a scale. It would be ridiculous to get the final result of 110.12333691 each time you stepped on the scale, so an analog system has to find a rounded figure to represent your weight to you as more comprehensible number such as 110, or 110 and so many ounces. In addition the way magnetic information is stored in an analog form has a certain amount of deterioration built in. An error such as a sudden drop in your weight down to 100 pounds would be equivalent to the types of deterioration which can occur in an
analog system. A digital system will give the same results every time, and the information gathered will never degenerate past that point in time, unless the recording medium develops glitches or there is an operator malfunction. If you record your weight each day on a sheet of paper, you are in essence keeping a digital record. No matter how many times you go back to that record, the number you have recorded for your weight will remain unchanged. A magnetic digital record is essentially the same. If error were to occur, for instance if the dog ate your sheet of paper, the record would disappear forever.

Since recent advances in microchip technology have increased sampling rates and removed some of the obstacles in the digital to analog conversion process, digital sound systems have become more practical. The proliferation of applications in electronic music synthesis has created a need to convey digital information among synthesis systems. The resulting impact of this musical sub-culture has been the development of the MIDI language, a standardization of digital code which facilitates communication between electronic instruments.

**MIDI**

The use of MIDI code as a system of connecting digital synthesizers and samplers (see below) is such a significant part of electronic music-making that it warrants some explanation. The word is an anagram for Musical Instrument Digital Interface. It is a digital coding system which transports coded data about pitch, amplitude, and other musical information from one place to another; that is, from synthesizer to synthesizer, or computer to synthesizer or sampler, and so on (Moog 1986:394). The creation of MIDI has been one of the strongest forces in shaping the electronic sounds we hear today, as it allows many electronic sounds to be played together and sequenced (see below), opening possibilities for new and innovative music.

In our classification system, a suffix (MIDI) indicating whether or not an electronic instrument is equipped with a MIDI interface and processor may be added to the instrument in question.
The first major category under the heading of electronophones is synthesizers, which includes any electronic instrument that produces self-generated sounds. **511 Analog synthesizer.** The first heading under synthesizers is analog, which includes all instruments that produce their sound either by using an electro-mechanical process or an oscillator circuit.
511.1. Electromechanical instruments include those that either utilize a disk with an inscribed waveform pattern (tone-wheel) or photoelectric film to generate their sound. Examples of these include the Cahill Tellharmonium and the Hammond organ. Many instruments in this category are fully polyphonic, that is, the only limit as to the number of available tones is the number of notes available on the keyboard or other playing mechanism. However, our system also includes the theoretical possibility of a monophonic or partially polyphonic electromechanical instrument. Monophonic instruments are those capable of producing only one note at a time. Partially polyphonic indicates that there is an upper limit to the notes capable of being played simultaneously, usually five, six, or eight (Davies 1984a:664).

511.2. The second group under analog comprises those instruments that use some form of electronic oscillator to generate their sound. This group is also subdivided into monophonic, partially polyphonic, and fully polyphonic.

The development of microprocessors has made it possible for electronic instruments (particularly synthesizers) to store sounds in an on-board computer memory. It has also allowed for partial and fully polyphonic capabilities on synthesizers. A micro-processor is the central processing unit of a computer system which is constructed using one or more integrated circuits instead of the larger transistors or vacuum tubes necessary prior to the revolution in miniaturization (Chamberlain 1985:126). Thus, our numbering system will indicate whether an instrument has a micro-processor or not. Note that instruments with microprocessors do not necessarily have polyphonic capability or a computer memory, although most instruments with microprocessors have either one or the other, and often both.

512 Types of Digital Sound Synthesis Used for Music Making

512.1 Computer synthesis

There are actually three primary types of computer music synthesis techniques: direct, analysis-based, and manipulation of digitized sounds. Each process involves the conversion of sound into numerical form using either a digital to analog converter (DAC) for generating tones or an analog to digital process (ADC) to sample the sounds for analysis, regeneration, or modification.

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1. Davies (1984a) provides a wealth of information on electronic music instruments; many of the instruments mentioned here are found in his article. See it for further clarification.

2. Technically it is possible for a monophonic instrument to produce more than one simultaneous tone (if it has more than one oscillator) by tuning the oscillators to different pitches, but if the player depresses two keys, only one will send a voltage control signal to the oscillators, which will produce the same interval no matter which key is depressed.
Specialized music programming languages have been created for the composer to use in order to communicate musical ideas to the computer. All these methods involve a great deal of time and patience. For example, in direct synthesis, it can often take days to encode musical information into a computer-readable code and format before the composer finally gets the opportunity to hear the piece. This severe time limitation was probably a major factor in the popularization of voltage controlled synthesizers, which emerged in the mid-1960s. Computer instruments were originally monophonic, so each part of a piece had to be recorded separately. The final product was mixed together in a recording studio before performance. Walter Carlos’ recording *Switched-On Bach* (1968) was the first exposure the general public had to this type of electronic music (Chamberlain 1985:34-41).

Techniques of sound production

A computer may function as one of three types of signal processors: additive, subtractive, and modulation (Moorer 1977:5). Each of these may be considered a specialized design subsumed under the larger generic category of computer synthesis. In the additive type, combinations of waveforms (e.g., sine, square, or sawtooth) of various frequencies are summed together (layered one upon the other) to create a composite sound. Musical aspects of the sound, such as duration and envelope, are then manipulated in the creation of the music just as one would play any instrument but with much more freedom to create “unplayable” new configurations.

Subtractive synthesis, as its name suggests, works by removing frequencies from a spectrally rich sound such as a sawtooth wave. The modulation method generates groups of sinusoidal partials through trigonometric summations. In other words, it puts harmonics of particular frequencies together in way that simulates the natural interaction of sound waves in an acoustic instrument.

512.2 Self-contained central processing units (Microprocessor type)

The development of microprocessors was indeed a revolutionary advance in terms of electronic music. The added ability to create real-time polyphony was a major advantage. Also, the cost of computing power was drastically reduced. What once would have cost a composer many thousands of dollars and months of grant writing to acquire for his electronic music studio could now be purchased for only hundreds of dollars. Electronic music was transported from the labor-

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3. The sound envelope may be understood as the amplitude of the entire sound entity from attack through decay.
atories of academic composition to the marketplace and the mass media. The cultural ramifications of this development have yet to be investigated and discussed thoroughly by ethnomusicologists.

Most of what are commonly thought of today as synthesizers fall into the class of instrument which is a self-contained box including a keyboard and a central processing unit (CPU) which simulate the voltage controlled synthesis techniques used in early electronic music and include memory to recall and execute instructions involving the sounds the performer wants to produce. These instruments include both digital synthesizers and some of the analog synthesizers previously discussed. The earliest versions such as the Synclavier more closely resembled a computer with a peripheral keyboard. The Fairlight CMI and the PPG Wave Computer were also of this ilk. By 1974, the Oberheim company had introduced the completely self-contained unit with fully integrated electronics which were capable of some programmable sequencing effects. The Polymoog (an analog synthesizer), designed in 1974, was the first fully polyphonic synthesizer (Davies 1984b:682).

At present there are five main groups of the self-contained type of digital synthesizer. They can be characterized by the method of sound production employed by their respective central processing units: 1) FM timbre synthesizers generate musical sound using a version of the non-linear frequency modulation technique developed by John Chowning at Stanford University (Chowning 1976). Two signals may be manipulated to interact with each other to produce sounds which very closely approximate the sound of acoustic music instruments. The natural quality of this type of synthesis was exciting to musicians who previously had been uninvolved with the electronic music world. The four additional types include 2) synthesizers with digitally controlled oscillators (DCO), which use digital versions of popular analog waveforms such as the sawtooth or square wave; 3) vector synthesizers, such as the Prophet VS, which use a table of values known as a wavetable so that its digital processes are able to simulate the sound-producing mechanism used in the analog based electronic instruments mentioned above; 4) additive synthesis, as in the Kawai K5; and 5) phase distortion, produced when a cosine wave is altered to produce new waveforms.
52 SAMPLERS

In synthesizers, sounds are generated electronically through the creation and manipulation of sonic waveforms or digital representation of them. In samplers, on the other hand, the sounds (or "samples") are not created within the instrument itself but are recorded sounds from some external source which are fed into a sampling instrument. Once stored in the sampler, the sound can be accessed and played back. The sound source itself can be virtually anything: an acoustic instrument such as piano, drum, violin, or panpipe; a human voice or a barking dog; an airplane taking off or a glass window being shattered; or a purely electronic sound created on a synthesizer.

521. Technically, the term "sampler" is only appropriate in reference to digital sampling instruments. However, the current breed of digital samplers, which dates back just over a decade to the original Fairlight CMI, has its roots in a group of analog electronic instruments which also used recorded sounds as musical source material. Such instruments can be classified as analog samplers. The tape recorder was the original analog sampler. In musique concrète and subsequent forms of "tape music," recordings stored on magnetic tape were manipulated and combined through various techniques such as splicing, looping, and reversal, thus serving as the source material for musical compositions. Another type of analog sampler is represented by instruments from the 1960s like the Chamberlain and the Mellotron. These instruments allow for keyboard control of recorded sounds stored on magnetic tape. If a key on the keyboard is struck, a mechanism is activated, setting a particular tape loop into play.

522. In digital samplers, which have for the most part made their analog predecessors obsolete and have become standard equipment in the modern electronic music studio, digitally recorded sounds are stored in the instrument's
computer memory. Generally, the sounds are stored on computer disks. One disk can usually store a number of sounds. In sample players (instruments which play back pre-recorded samples, called presets, without allowing for the recording of new samples), sounds are stored in the instrument itself rather than on disks (i.e., hardware vs. software storage). The great popularity of digital samplers can be attributed to several factors including ease of programmability, unlimited range of possible sounds, the ultra-high fidelity of digitally recorded sampled sounds, and a potential for “natural-sounding” electronically generated sounds which is unattainable even with the most sophisticated forms of synthesis.

Digital samplers, like digital synthesizers, generally allow for numerous sound editing processes. For example, on the Roland S-50, an original sampled sound can be looped, truncated, reversed, transposed, combined with another sample, assigned to any combination of keys on the keyboard, etc. Modern samplers are generally MIDI-equipped so that they can function in systems where they are connected to MIDI controllers (see below), computers, and synthesizers. Like synthesizers, samplers can be either self-contained (i.e., keyboard samplers) or they can be dependent instruments (i.e., rack-mount samplers like the Akai S900) that are activated by an external controller (e.g., a synthesizer keyboard, a “dummy” keyboard, or an electronic wind instrument).

Some of the basic specifications which determine the quality of particular samplers are sampling time, rate, and resolution. Sampling time is simply the length of the recorded sample. This may range from less than a second (e.g., 0.4 seconds) to over a minute. The highest quality samplers allow for the longest sampling time at the highest rate and resolution. Sampling rate refers to the number of samples of a sound which the sampler records in a second. A digital sample is like a series of snapshots of a soundwave as it progresses through time. The closer together these “snapshots” are, the better the sound quality will be, since a higher rate leads to a closer digital approximation of the original analog soundwave. Sampling rates are measured in KHz (Kilohertz). A sampling rate of 44,000 samples/second equals 44 KHz. Most instruments allow the user a choice of two or more sampling rates. For example, on the Roland S-50, one has the choice of sampling up to 14 seconds per disk at 30 KHz or up to 28 seconds at 15 KHz. This is called variable sampling rate. The final major specification, sampling resolution, relates to the degree of accuracy in sampling the voltage of the sound wave. The voltage level of each individual sample is measured and encoded as a number, using a sequence of “1”s and “0”s called binary digits or “bits.” Depending on the quality of the sampler, the number of “bits” per sample will be eight, twelve, sixteen or more (e.g., 1011 0001 is an 8-bit number because it consists of eight binary digits). A processor with 16-bit resolution will produce a more accurate sample than an 8-bit instrument. Factors such as the rate of sampling, the sampling resolution, and the frequency range of the sound that is being measured interact to effect the fidelity of the final sound.
53 HYBRIDS

While the majority of sound-generating electronic musical instruments can be classified as digital or analog, synthesizer or sampler, a number of relatively recent instruments are notable for having crossed boundaries by combining different synthesis techniques. We are referring to these as “hybrids” because of the combination of techniques. These instruments have in common the use of a method of sound generation in which digital wavetable oscillators mimic the function of analog oscillators, creating digital versions of the various waveforms generated in analog synthesis: sawtooth, square, modulated pulse, triangle, and sine waves.

Hybrids are among the newest developments in electronic music instruments. There is some confusion because the technology is changing daily and manufacturers often apply different names to similar processes. One category of hybrids is digital synthesizers, which mimic analog waveform generation using various processes. Examples include the Ensoniq ESQ1 and PPG Wave which use wavetable synthesis (531). Cross-table sampling (532) (e.g., Keytek CTS 2000) is the process by which a digitally modified sample is put into a wavetable and then the wavetable or a combination of wavetables are used to create the sound. Structured adaptive synthesis (533) (e.g., Roland RD1000 digital piano) uses digital algorithms to simulate the complex acoustic phenomena (resonance, sympathetic vibrations) of an acoustic piano. Linear arithmetic synthesis (534) (e.g., Roland D50) combines four “partials,” which are either digital waveforms or sampled sounds, to create a complex sound.

Another category of hybrids (535) combines wavetable synthesis with digital sampling (e.g., Korg DSS1, Casio FZ1, Sequential Prophet 2000/2002, Roland D50). The aforementioned Roland D50, for example, contains two sets of oscillators: one set of digital oscillators play back analog-type sawtooth and square waves, and another set plays back the sampled attack of a sound, often going into a loop of the sound. This results in the creation of digitally produced synthesis which combines a digitally sampled attack with an analog-type sound.
SUFFIXES

We propose five groups of suffixes which may be appended to any electronic phone classification number in order to supply further details about the instruments. The first indicates what kind of on-board (built-in) apparatus is used to play the instrument (as opposed to an external controller—see below). The most common (K) is a keyboard, but other types also exist and are listed in Appendix A. The next suffix indicates whether the instrument's sounds are preset (Ps), user-adjustable (Ua), or both. The third suffix (My) indicates whether the instrument has memory capability. Often, instruments with an on-board memory capability come with factory-supplied presets as well as being user-adjustable, hence the preponderance of the Ps/Ua-My combination. The fourth suffix (T) indicates whether the instrument is touch sensitive or not. Touch sensitivity means that different sound parameters will be affected depending on how hard or how fast the keys are pressed. The fifth suffix indicates whether the instrument is MIDI equipped or not. (See the end of Appendix A for a full list of categories and subcategories.)

CONTROLLERS

A controller is the instrument on which electronic music is actually performed. Controllers can either be built into the instrument (internal) or can be separate non-sounding units interfaced to sound-generating devices (external). On a keyboard synthesizer, the built-in piano-type keyboard is an internal controller. A “dummy” piano keyboard such as the Yamaha KX88, on the other hand, which triggers synthesizers via MIDI but has no sounds of its own, is an external controller. In recent years, a host of new controllers have been designed to meet the performance needs of virtually all types of instrumentalists.

These controllers are designed to interface with any of the sound generators previously discussed. For this reason, we are assigning suffixes to them to avoid confusion; otherwise they could conceivably be placed into every category. Since they have been designed as electronic counterparts to acoustic instruments (allowing for many of the expressive capabilities of non-keyboard instruments not otherwise attainable), it is convenient to class them more or less in categories relating to Horndestel-Sachs: Kc = keyboard controller, Pc = percussion controller, Ac = aerophone controller, and Cc = chordophone controller. The lower case c in the suffix will indicate reference to an external controller. This will avoid confusion between K (on-board keyboard controller) and Kc (external or dummy keyboard controller).
Examples of external controllers:

- EVI, EWI, Lyricon, WX7 (aerophone controllers)
- Yamaha KX88 (keyboard controller)
- Simmons electronic drums and KAT, a xylophone-type MIDI controller (percussion controllers)
- Yamaha and Roland (analog) guitar synthesizers (chordophone controllers)

In addition to controller instruments, there are various accessory controller devices (ACDs) such as the DX7 "breath controller," which allows the keyboardist to change dynamics and add tonal inflections to his performance by means of blowing into a small external mouthpiece which is connected to the keyboard. For a complete listing of controller suffixes, see the end of Appendix A.

**Modifiers**

Modifiers are electronic devices which modify either the electronic signals prior to their conversion into sound or the compositional organization of sounds created by electronophones and other music instruments. They are not sound producers, therefore we have assigned them to an adjunct category within the entire music-making system. These devices are assigned a number in a manner parallel to the Hornbostel-Sachs scheme, prefaced by the letters MOD. Since this proposed method is modular, a modifier may be appended to any existing instrument classification by means of a plus sign.4 We suggest two major subdivisions of modifiers: music processors and sound processors. In this article, we are dealing only with electronic modifiers.

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4. If one were to attempt the classification of an entire music-making process, each element could be classified in a similar manner: performer (PER) + instrument (INST) + modifier (MOD) + acoustic space (AS) + receiver (REC).
MOD. 1 MUSIC PROCESSOR

Music processors, classified emically by their users as sequencers, function like tape recorders which play back whatever you play or program into them. Unlike a tape recorder, however, the sequencer actually "plays" the instrument(s) to which the recorded musical information is sent. The sequencer records musical data rather than musical sound, then sends this data back into sound generators (i.e., synthesizers and samplers) where the data is converted into a musical performance. Sequencers can be built into an instrument (Korg M1), can exist as a separate piece of hardware interfaced with instruments (Roland MC-4, Alesis MMT-8), or can be in the form of computer software (Mark of the Unicorn's "Performer"). Generally, sequencers are "multi-track" devices, that is, several parts (i.e., "tracks") can be inputted separately and then played back simultaneously. There are two basic methods of sequencing: step-time and real-time. In a step-time sequencer, notes are programmed in one at a time. Each note is assigned a particular pitch and duration. Other parameters, such as dynamics, degree of touch-sensitivity, and assignment of instrument to which a particular musical track is to be sent may also be programmed. (Note: different sequencers allow for control over different parameters). In real-time sequencing, the composer actually performs the various musical parts track by track on MIDI-equipped instruments. The performance is recorded as digital information by the sequencer which can then "perform" the entire composition as it was originally played, either on the original performance instrument(s) or on any other MIDI instruments with which it is interfaced.

Sequencers have acoustical antecedents in instruments like player pianos and music boxes. Just as the activation of a player piano roll will result in a performance of the programmed piece on an acoustic piano, the activation of a sequencer will result in the performance of a sequenced composition on synthesizer(s).
MOD. 11 Analog. Sequencers, like synthesizers, can be either digital or analog. The use of punch cards in the famous RCA Synthesizer, invented in the late 1950s at the Columbia-Princeton Music Center, exemplifies analog sequencing. Here, the synthesizer's reading of the inputted punch card resulted in the musical performance, much like a player piano's "reading" of the punches in a piano roll determines musical performance. All analog sequencers were limited to step-time sequencing. All the information had to be programmed note by note. Real-time performance was not possible. Furthermore, the memory capabilities of analog sequencers were relatively limited.

MOD. 12 Digital. Digital, microprocessor-controlled sequencers came on the scene in the mid-1970s with the introduction of the Roland MC-8. These devices had greatly expanded memories, increased polyphonic capabilities, and more sophisticated programming features, although they were still difficult to program and only allowed for step-time sequencing.

Real-time sequencing was introduced in the Fairlight CMI Series I in 1979 with its Page "R" (i.e., "Real-time") sequencer. Sequences of up to eight tracks could be performed "live" on the Fairlight's piano-type keyboard. Page "R" would record the sequence and then play it back in its entirety. It was then possible to edit various parameters of the original performance such as tempo and rhythm. Rhythmic editing was accomplished through quantization, in which the real-time rhythmic performance could be converted into a "perfect" metronomic performance by the computer, making the real-time performance sound essentially like a step-time performance. The Fairlight was also equipped with an eight-track step-time sequencer.

The MIDI-implementation of personal computers in the mid-1980s has led to a proliferation of software sequencers, some of which are incredibly sophisticated. Mark of the Unicorn's "Performer" is one of the best and most popular, with its extensive recording and editing features (quantization sensitivity and strength, note correction, cutting and pasting, note lengthening and shortening, etc.). (For a more detailed discussion of sequencers, see Bakan 1988:177-84.)

In the category of sequencers, it is necessary to mention drum machines and "canned" drums. Drum machines combine a sequencer with synthesized or sampled percussion sounds (usually presets). It is possible to create one's own drum patterns (or use preset patterns) and link them together into complete drum parts for songs. We use the term "canned" drums to refer to the preset drum patterns ("rock," "tango," "samba," etc.) on electronic organs and "consumer synthesizers" like the little Casiotones sold at Radio Shack. Drum machines are indicated by the suffix D and further clarified through the use of the Ps/Us suffixes. (See modifier suffixes at the end of Appendix A.)
Sound processors can be defined as any electronic device that modifies or alters the basic sound of the instrument. Included under this heading are such items as reverb units, graphic equalizers, and foot-pedal effects boxes (stomp boxes).

The first criterion by which sound processors are classified is whether they are analog or digital. Under each of these two headings sound processors are further subdivided according to the basic sound-modifying function they serve. These are: 1) amplitude modifiers, 2) pitch modifiers, 3) time or temporal modifiers, and 4) timbral modifiers. Amplitude modifiers are any devices that alter the loudness of the instrument, for example volume pedals or compressor/limiters. Pitch modifiers alter the pitch of the sound in some way. Temporal modifiers are any devices that use a time-delay technique to modify the sound of the instrument. Chorus, flangers, and delays all employ this technique to create a doubling effect. Reverb units simulate the time-delay effect of sound bouncing off the walls of an enclosed space. Finally, timbral modifiers (e.g., the APHEX aural exciter) adjust the timbre of the sound by boosting or attenuating certain frequencies or by simulating amplifier saturation (i.e., overdrive or distortion). These can be either real-time (e.g., the Boss “Octave” and the Eventide Harmonizer) or MIDI (e.g., the Fairlight voice-tracker and others) which can add up to five parallel voices above or below the tone being played by the instrument to which it is attached.
CONCLUSION

It has not been our intention to present here the definitive classification system for electronic music instruments. Instead, we have suggested a model which we hope will stimulate ethnomusicologists to embrace music electronics in their research and to provide a basic understanding which can be incorporated into their teaching. In addition, we hope that the system will be flexible enough to accommodate the inevitable changes which are occurring and will continue to occur in the field of music electronic technology.

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Moog, Robert

Moorer, James A.

Nettl, Bruno

Sachs, Curt

Takanuma, Toshie

Vaughn, Kathryn V.
APPENDIX A

THE GAMES CLASSIFICATION SYSTEM OF ELECTRONOPHONES
IN OUTLINE FORM

5 ELECTRONOPHONES

51 Synthesizers
511 Analog
511.1 with electromechanical tone generators
511.11 tone wheel
511.111 monophonic
511.112 partially polyphonic
511.113 fully polyphonic
511.12 photoelectric
511.121 monophonic
511.122 partially polyphonic
511.123 fully polyphonic
511.2 with oscillators
511.21 without micro-processors
511.211 monophonic
511.212 partially polyphonic
511.213 fully polyphonic
511.22 with micro-processors
511.221 monophonic
511.222 partially polyphonic
511.223 fully polyphonic

512 Digital
512.1 computer synthesis
512.11 with micro-processors
512.12 direct synthesis
512.13 with voltage control attenuators
512.2 self-contained CPUs
512.21 additive
512.211 partially polyphonic
512.212 fully polyphonic
512.22 digital controlled oscillators
512.221 partially polyphonic
512.222 fully polyphonic
512.23 frequency modulation
512.231 partially polyphonic
512.232 fully polyphonic
512.24 phase distortion
512.241 partially polyphonic
512.242 fully polyphonic
512.25 vector synthesis
512.251 partially polyphonic
512.252 fully polyphonic
52 Samplers
521 Analog
  521.1 magnetic tape
  521.11 manual
  521.12 automatic
522 Digital

53 Hybrids
531 wavetable synthesis
  531.1 partially polyphonic
  531.2 fully polyphonic
532 cross-table sampling
  532.1 partially polyphonic
  532.2 fully polyphonic
533 structured adaptive synthesis
  533.1 partially polyphonic
  533.2 fully polyphonic
534 linear arithmetic
  534.1 partially polyphonic
  534.2 fully polyphonic
535 combination hybrids
  535.1 partially polyphonic
  535.2 fully polyphonic

MODIFIERS

MOD. 1 Music Processors
11 Analog
  11.1 step-time
  11.11 software
  11.12 hardware
12 Digital
  12.1 step-time
  12.11 software
  12.12 hardware
  12.2 real-time
  12.21 software
  12.22 hardware

MOD. 2 Sound Processors
21 Analog
  21.1 amplitude modifiers
  21.1 pitch modifiers
  21.3 temporal modifiers
  21.4 timbral modifiers
22 Digital
  22.1 amplitude modifiers
  22.2 pitch modifiers
  22.3 temporal modifiers
  22.4 timbral modifiers
LIST OF SUFFIXES

Acoustical Instruments
  A = Amplified
  E = Electric

Electrophones
  Group 1
    K = keyboard
    R = rods
    Rm = rack mount (no on-board controller)
    P = pads or plates
    B = buttons

  Group 2
    Ps = preset
    Ua = user-adjustable

  Group 3
    My = on-board memory

  Group 4
    T = touch sensitive

  Group 5
    MIDI = equipped with Musical Instrument Digital Interface

Controllers (External)
  Wc = wind controller
  Cc = chordophone controller
  Kc = keyboard controller
  Pc = percussion controller
  T = touch sensitive

Accessory Controller Devices (ACDs)
  Bc = breath controller

Modifiers
  D = drum machine
  Ps = preset
  Ua = user adjustable
APPENDIX B

THE GAMES CLASSIFICATION SYSTEM OF ELECTRONOPHONES IN GRAPH FORM

5 ELECTRONOPHONES

51
- synthesizers

52
- samplers

53
- hybrids

511
- analog

511.1
- with electromechanical tone generators

511.11
- tone wheel
- monophonic
- partially polyphonic
- fully polyphonic

511.12
- photoselectric
- monophonic
- partially polyphonic
- fully polyphonic

511.21
- without micro-processors
- monophonic
- partially polyphonic
- fully polyphonic

511.22
- with micro-processors
- monophonic
- partially polyphonic
- fully polyphonic

digital subdivisions on following page

with oscillators
APPENDIX C

SOME WELL-KNOWN ELECTRONIC INSTRUMENTS CLASSIFIED ACCORDING TO THE GAMES SYSTEM.

<table>
<thead>
<tr>
<th>Analog synthesizers</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Minimoog</td>
<td>511.211 K-Ua</td>
</tr>
<tr>
<td>Hammond B-3 Organ</td>
<td>511.113 K-Ps</td>
</tr>
<tr>
<td>Prophet 5</td>
<td>511.222 K-Ps/Ua-My</td>
</tr>
<tr>
<td>Yamaha CS20M</td>
<td>511.221 K-Ps/Ua-My</td>
</tr>
<tr>
<td>Elepian Electronic Piano</td>
<td>511.213 K-Ps-T</td>
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<td>Theremin</td>
<td>511.211 R-Ps</td>
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<table>
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<tr>
<th>Digital Synthesizers</th>
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<tbody>
<tr>
<td>Yamaha DX7</td>
<td>512.231 K-Ps/Ua-My-T-MIDI</td>
</tr>
<tr>
<td>Kawai</td>
<td>512.211 K-Ps/Ua-My-T-MIDI</td>
</tr>
<tr>
<td>Yamaha TX81Z</td>
<td>512.231 Rm-Ps/Ua-My-MIDI</td>
</tr>
<tr>
<td>Roland Juno 6</td>
<td>512.221 K-Ua</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Samplers</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Roland S-50</td>
<td>522 K-Ps/Ua-My-T-MIDI</td>
</tr>
<tr>
<td>Akai S-900</td>
<td>522 Rm-Ps/Ua-My-MIDI</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hybrids</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Roland D50</td>
<td>534.1 K-Ps/Ua-My-T-MIDI</td>
</tr>
<tr>
<td>Roland RD1000</td>
<td>533.2 K-Ps/Ua-My-T-MIDI</td>
</tr>
<tr>
<td>Casio FZ1</td>
<td>512.211 + 522 K-Ps/Ua-My-T-MIDI</td>
</tr>
<tr>
<td>Keytek CTS-2000</td>
<td>532.1 K-Ps/Ua-My-T-MIDI</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Music Processors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairlight CMI Page &quot;R&quot;</td>
<td>MOD. 12.2</td>
</tr>
<tr>
<td>Oberheim DMX</td>
<td>MOD. 12.2-D-Ua</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sound Processors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Boss Octaver</td>
<td>MOD. 21.2-Ua</td>
</tr>
<tr>
<td>Boss Heavy Metal</td>
<td>MOD. 21.4-Ua</td>
</tr>
<tr>
<td>Fairlight voice-tracker</td>
<td>MOD. 22.2-Ua</td>
</tr>
</tbody>
</table>
APPENDIX D

RECOMMENDED LISTENING

For those whose curiosity has been piqued by this article, here is a short list of some recordings that illustrate some of the many ways that electronic music technology has been explored.

John Cage
Walter Carlos
Miles Davis
Brian Eno
King Crimson

Kraftwerk
King Tubby
Madonna
Mannheim Steamroller
Public Enemy

Clara Rockmore
Klaus Schulze
Jimmy Smith
Mark Stewart + Maffia

Karlheinz Stockhausen
Sun Ra
Throbbing Gristle

Indeterminacy (Folkways FT 3704)
Switched-On Bach, Vol. 1 (Columbia MS 7194)
Live at Fillmore (Columbia CG 30038)
Another Green World (Editions EG 2302 069)
In the Court of the Crimson King (Editions EG EGKC 1)

Trans-Europe Express (Capitol SW 11603)
Dub from the Roots (TSL 106)
Like A Virgin (Sire 25157)
Fresh Aire II (American Gramophone AGCD 359)
It Takes A Nation of Millions to Hold Us Back
(Def Jam CK 44303)

Theremin Virtuoso (Delos DEL 25437)
Moondawn (Ariola 275566T)
Midnight Special (Blue Note BST 84078)
As the Veneer of Democracy Starts to Fade
(Mute STumm 24)

Hymnen (Deutsche Grammophon 2707 039)
Live in Paris 1970 (Recommended RR 11)
Twenty Jazz Funk Greats (Mute MIR 003)