THE ELECTRONIC SOUND STUDIO OF THE 1970'S

by

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THE future will add the digital computer to the equipment of today's electronic studio. In the near future it will control analogue sound synthesizers. Together the digital and analogue devices form a hybrid sound synthesizer. In the far future analogue devices may be swept away by more reliable and accurate digital synthesizers constructed from integrated circuits. The result will be real-time digital synthesizers which can be played with all the nuances of present-day performance and all the precision and range of sound quality achieved by present-day digital synthesis. The future grows from the past, and the past is now long enough to reveal at least the next step forward.

Today, two major approaches to sound synthesis exist. The first and oldest grew from manipulation of sounds recorded on tape — splicing, tape loops, and speed changes. These methods were combined with electronic modification of sounds — mixing, filtering, modulation, reverberation, and enveloping. Electronic sound sources — oscillators and noise generators — were added. A culmination of these trends is the electronic sound synthesizer as typified by the Moog (1) and Buchla (2) devices. These machines contain several pregnant innovations. Voltage controlled oscillators, whose frequency is determined by a voltage rather than with a knob can be interconnected so as to produce much more interesting wave-forms. Voltage controlled amplifiers whose gain is controlled by a voltage can be used to impose attack and decay patterns on other sounds. Voltage controlled filters effect continuous timbre changes. Keyboards and sequencers provide facile sources of control voltages which can be used not only to determine pitch, but also timbres and other musical factors. Multitrack tape recorders — 16-track machines are not uncommon — are the powerful medium with which multiple voices are combined and mistakes edited out. Records such as « Switched-on Bach » (3) testify to the

(1) R. A. MOOG, « Electronic Music, Its Composition and Performance », *Electronics World*, February 1967. Product Catalogue, R. A. Moog Co., Trumansbrug, N. Y. 14886.
(2) Product Literature, CBS Musical Instruments, Inc., 1300 East Valencia Drive, Fullerton, California 92631.
(3) « Switched-On Bach », Columbia Records, MS7194.

power of this medium. Its limitations vis-à-vis all digital synthesis lie in the limited range of sound qualities inherent in the physical equipment and in the necessity to generate control voltages in real time by manual manipulations.

The second and younger approach is all-digital sound synthesis (4). The principles are shown on Fig. 1. A programme computes the many numbers which are samples of the actual sound wave to be heard. These numbers are read out of the computer at a high speed (30,000 numbers per second to fabricate a sound with a bandwidth of 15,000 Hz) and put into a digital-to-analogue converter. The output voltage from the converter is smoothed by a filter and applied to a loudspeaker which directly generates the desired soundwave. The process can produce any sound that could conceivably originate from a loudspeaker.

Programmes to generate sounds are highly developed. Block diagrams of two programmes in the form of simulated instruments are shown on Fig. 2. The simple instrument consists of two OSC oscillators. Each OSC has two inputs, the left-hand input controlling its amplitude, the right-hand input controlling its frequency. The waveshape is specified by one cycle of waveform stored in the computer memory (F1 and F2). In this particular instrument, the lower OSC provides a truncated square wave as the basic waveshape for the sound. The upper OSC provides an attack and decay for the notes according to waveshape F1. Its frequency is set to be 1/(Note Duration) so it goes through exactly one cycle of oscillation per note. The more complicated instrument on Fig. 2 illustrates normal complexities used by composers. We shall not discuss its operation. A catalogue (5) of sounds produced by various instruments already exists.

The simulated instruments are formed by unit generators — oscillators, adders, multipliers — which can be interconnected in any way by the composer. The generators are controlled by input numbers. Thus they are the computer equivalent of the voltage controlled oscillators and other devices in analogue synthesizers. This similarity will soon be exploited in hybrid synthesizers.

By comparison with analogue synthesis, today's digital synthesis is more precise, allows a wider range of sound qualities, and make no demands of performance speed. However, computer time is expensive and the composer suffers a certain remoteness from his sounds. Scores are punched on decks of computer cards and later the finished unalterable sound emerges from the computer. Performance nuance and real time adjustment of sound qualities are impossible. The hybrid synthesizer solves these basic problems, combining the advantages of analogue and digital synthesis.

(4) M. V. Mathews, *The Technology of Computer Music,* M. I. T. Press (1969).

(5) J. C. Risset, « An Introductory Catalogue of Computer Sounds », Bell Telephone Laboratories, Incorporated, Murray Hill, N. J. 07974.

Existing hybrid synthesizers (6) (7) already demonstrate many attractive potentialities. The basic approach is shown on Fig. 3. A digital computer is equipped with real time inputs which can be played by the musician-performer. A group of digital-to-analogue converters provide a number of control signals for an analogue synthesizer. Sound from the synthesizer is heard directly by the performer so he can adjust sound qualities in real time and can inject the amount of performance variation which he chooses. The control signals to the analogue synthesizer are of sufficiently low bandwidth so a much lower sampling rate from the converter is needed and hence, the speed of the computer can be lower. A cheaper computer may be used than that needed for all-digital synthesis. The computer provides great flexibility in relating the musician's inputs to the analogue synthesizer control.

To make concrete these potentialities we will describe the Groove (7) system in some detail. Fig. 4 shows a block diagram of the digital part of the Groove machine (8). The DDP-224 is a medium-sized computer with a 32,000 word, 24-bit, 1.7μs memory. The main secondary memory is a CDC-9432 disc file with removable disc packs which store 2,000,000 computer words and transmit 1200 words in 30ms. Such a store is a central part of Groove. The removable disc packs are a boon to the many users of the computer since each can have his own pack. A typewriter provides control input. The magnetic tape is used only as back-up memory for the disc file.

Twelve 8-bit and two 12-bit digital-to-analogue converters form the principal outputs of Groove. Sixteen relay controls are also provided. Two additional converters supply the X and Y deflection voltages to a cathode ray tube which displays the computer « score ».

At present Groove inputs 7 voltages. Four come from rotary potentiometers or knobs which may be turned by the operator in real time. Three come from a 3-dimensional linear wand. These real-time inputs are called knob inputs. A 24-key organ keyboard provides a familiar and very useful input for keyboard players. Each key sets a bit in the 24-bit computer word — multiple keys may be simultaneously depressed and read.

An external oscillator controls the sampling rate of the output functions thus controlling the tempo of the sound changes without affecting any other qualities such as pitch.

The analogue half of Groove is diagrammed on Fig. 5. A central patchfield with removable patchboards interconnects the various elements and allows different users to quickly insert their own patchboards. The 14 analogue outputs of the computer and contacts on 16 computer-controlled relays terminate on the patchfield. Twelve voltage-controlled oscillators, 7 voltage-

(6) P. Zinovieff, Electronic Music Studio, 49 Deodar Road, London, S. W. 15, England.

(7) M. V. Mathews and F. R. Moore, « GROOVE - A Program to Compose, Store, and Edit Functions of Time », (Forthcoming in *ACM Proceedings*).

(8) The configuration was developed to carry out speech synthesis studies at the Bell Telephone Laboratories.

controlled amplifiers, and two voltage-controlled filters are standard components. Much signal processing is done by 72 operational amplifiers using well-known techniques of analogue computers. Both the amplifiers and their attached networks are built on plug-in cards. Each card is designed for a particular function. We will give examples of their use later. Fifty 10-turn potentiometers with precise dials set the constants associated with the operational amplifier and allow different users to reset their constants with relative ease. Connexions to a pre-existing audio patchfield augment the Groove equipment with a traditional mixing panel and reverberator.

We have now described the equipment in a system capable of real-time sound synthesis by a computer-controlled synthesizer. But we have not yet said how this system is used to transcend the limitations of existing synthesizers or digital synthesis. The possibilities of real-time sound synthesis are clear. But we do not wish to again impose on the musician all the dynamic demands of real-time performance. A new philosophy to utilize the digital control computer is demanded. We have called this philosophy the « Conductor » concept.

The conductor concept maintains that the desired relation between the performer and the computer is not that between the player and his instrument, but rather that between the conductor and the orchestra. The conductor does not personally play every note in a score, instead he influences (hopefully controls) the way in which the instrumentalists play the notes. The computer performer should not attempt to define the entire sound in real time. Instead, the computer should contain a score and the performer should influence the way in which the score is played. His modes of influence can be much more varied than that of a conventional conductor who primarily controls tempo, loudness, and style. He can, for example, insert an additional voice of his own, or part of a voice such as the pitch line while the computer supplies the rhythm. The mode of conducting consists of turning knobs and pressing keys rather than waving a stick, but this is a minor mechanical detail.

The computer should do more than follow the conductor ; it should also remember all the conductor's functions so when he achieves a desired performance, it can be repeated from memory. Furthermore, it should allow the conductor to edit or change any part of the conductor functions, or of the score functions. (Actually the score functions are computationally indistinguishable from the conductor functions.)

The conductor concept led to the features which are incorporated in the Groove programme. The programme is basically a system for creating, storing, retrieving, and editing functions of time. It allows the composition of time functions by turning knobs and pressing keys in real time ; it stores time functions on the disc file ; it retrieves the stored functions (the score) combines them with input functions (the conductor functions) in order to generate the control functions which drive the analogue synthesizer ; and it provides for facile editing of time functions via control of « programme » time.

Pages of a Groove score are numbered in the upper right-hand corners as normal scores are numbered. Up to about ten functions can be displayed without crowding the display and any functions can be selected for display. The way in which functions are used to control the analogue synthesizer are defined by the composer by typing statements on the typewriter (7), but for this example we can think of these functions as controlling the pitch of three voltage-controlled oscillators.

As the composition is played, the successive pages of the score appear on the scope analogously to turning the pages of a normal score. The sounds being played at the current instant are indicated by the vertical column of bright dots (as well as being heard on the loudspeakers). The dots sweep across the page from left to right as a conductor's eyes might sweep across a page of normal score. Time in the score may be frozen by pushing a key. Motion of the dot column stops at this point in the score and the analogue synthesizer sustains whatever sound it is playing. The conductor can then edit the score and change any functions he desires. He both hears and sees the changes as they are made. He can also put « score time » under knob control and move either forward or backward on a page under control of a knob.

The digital part of Groove has other important features concerning periodic functions and a compositional algebra which are elsewhere described (7).

One of the problems which must be surmounted by Groove (and other analogue synthesizers) is a limited selection of tone qualities. Unless the composer is ingenious and careful, too many voices sound like square waves modulated by various attack and decay rates. All-digital synthesis achieves its tonal power through the use of unit generators. Instead of providing the composer with fixed instruments, it gives him unit generator building blocks from which he can (and must) assemble his own instruments. The operational amplifiers in Groove make possible a similar construction.

An example of a Groove instrument patched together from operational amplifiers, oscillators, and voltage-controlled amplifiers is shown on Fig. 6. It produces a string-like tone quality and provides for double stops. Six control signals from the computer are required. C1 and C2 determine the amplitude and pitch of the first « string » ; C3 and C4 supply the same functions for the second « string » ; C5 and C6 control the amplitude and frequency of a vibrato which modulates the frequency of both « strings ». The function of most of the components is obvious. The exponential transform is a diode network attached to an operational amplifier so the computer control will be in steps of equal pitch — the oscillators have a linear voltage-frequency characteristic. The Bow Waveform Shaper is a nonlinear operational amplifier network which transforms the oscillator waveform to one more characteristic of a bowed string. Resonances typical of stringed instruments and the attack-decay generator are easily constructed with operational amplifiers.

The close resemblances between the Groove instrument and the simulated instruments shown on Fig. 2 for all digital synthesis are obvious. For example, the combination of a voltage controlled oscillator and voltage controlled amplifier is closely equivalent to a simulated OSC unit generator. The bow waveform generator introduces at least some of the flexibility inherent in the stored waveforms of OSC. The resemblance is close enough so almost all the instruments developed in Risset's sound catalogue can be mapped directly onto Groove instruments. This is indeed a very powerful collection of sounds. Moreover, a number of operations such as resonant filtering and reverberation are more easily done with Groove than with digital simulation.

The Groove system has proven to be so powerful, so rapid, and so pleasant to use that we have no hesitation in predicting that the hybrid computer — a digital device driving an analogue synthesizer — will be the central facility in the electronic studios of the immediate future. Such a system will provide :

1. The power and logic of digital control and digital memories for driving analogue synthesizers.
2. Real-time sound synthesis allowing both improvisation and performance nuance. Performances will be recorded in digital memories and can subsequently be revised and perfected.
3. Good sound quality by means of unit generators constructed from operational amplifiers.

Existing sound synthesizers and the operational amplifier techniques which are well known in the analogue computer art form a strong foundation for sound synthesis. Present-day small computers are entirely adequate for control purposes. They must have an adequate secondary storage medium in the form of a disc file and must have enough input-output channels to accommodate digital-analogue conversion. These features are readily available.

Groove-type systems have two inherent limitations. First, the accuracy of the analogue equipment, particularly the frequency stability of the oscillators is barely sufficient for some musical purposes. Second, even with removable patchfields, set-up and adjustment time of a complicated orchestra may take an hour. Consequently, if many people are using a single studio, much time is wasted in setting up the different users' orchestras. Both limitations can be removed by replacing the analogue equipment with an all-digital synthesizer. It would have the high accuracy of digital equipment and could be set up by a deck of cards read by the computer. At the moment, an all-digital synthesizer may be too expensive for electronic studios. However, integrated circuits promise price reductions. If they actually come forth, we predict an all-digital real-time music machine. In the interim, certain critical components such as oscillator frequency control may be done digitally.

It is clear that the electronic studio of the future will place great technical demands on the composer. In addition to being a good computer programmer, he must learn the analogue computer art from electrical engineering. It is in

many ways more complex than digital computer programming. These diverse skills may be unreasonable to ask of a musician. If so, a possible alternative is composition by a team consisting of a musician and an engineer.

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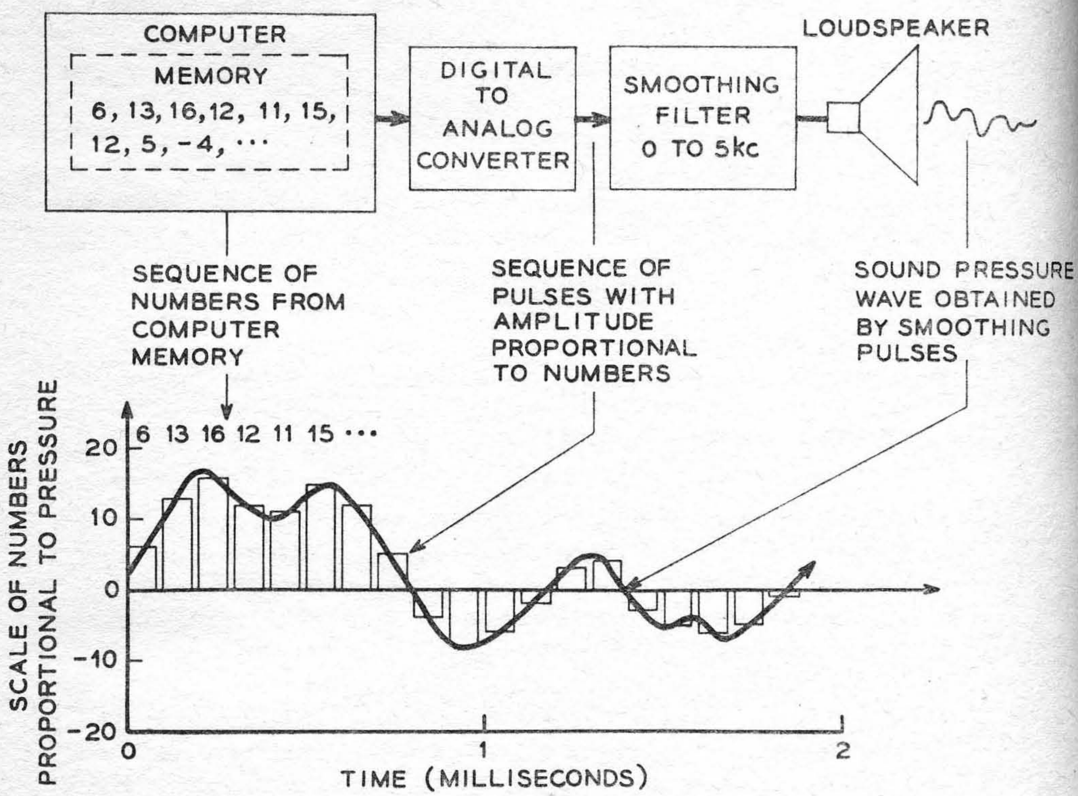

Fig. 1. *Principles of all-digital sound synthesis.*

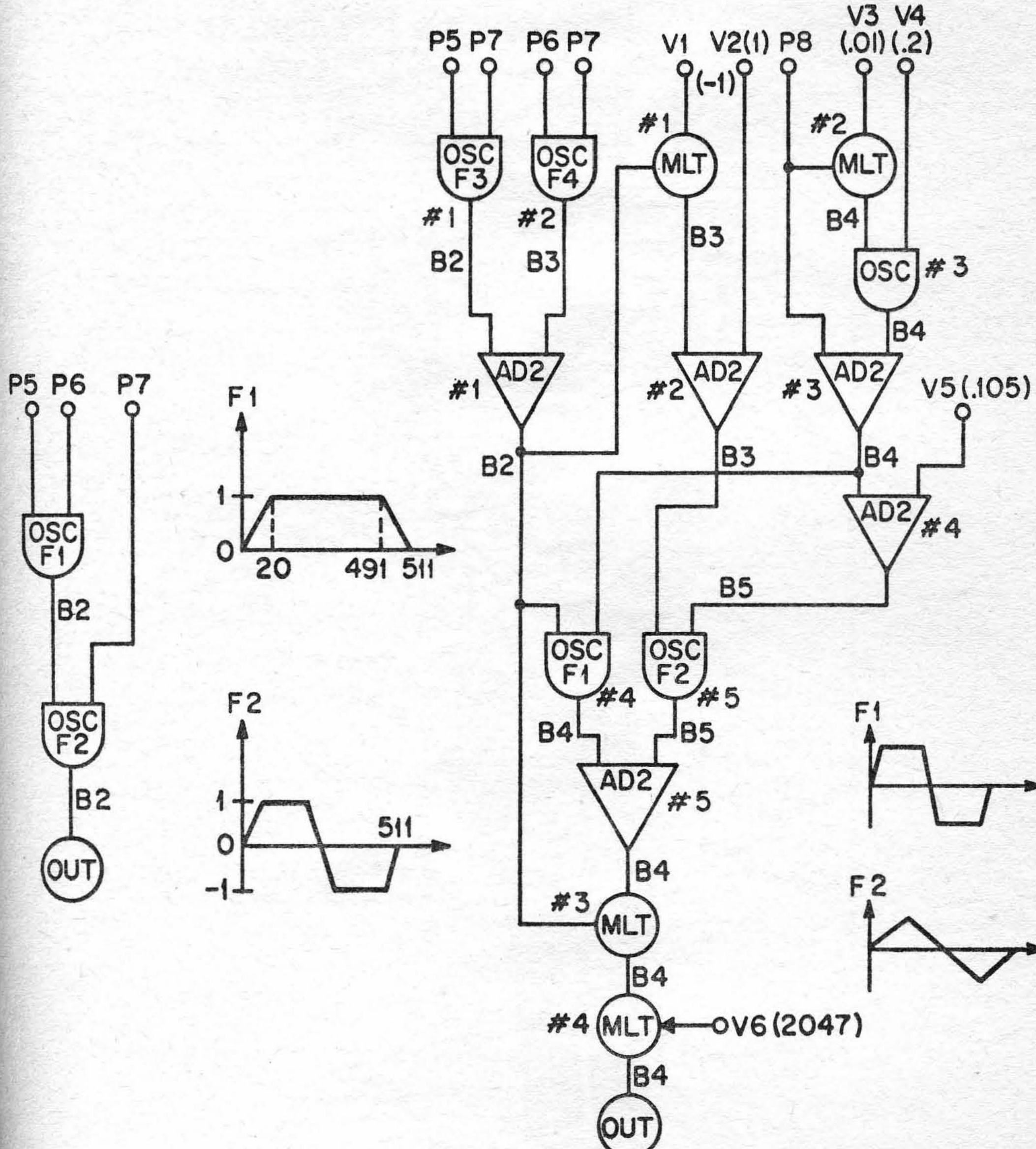

Fig. 2. *Two simulated instruments for Music V digital synthesis programme.*

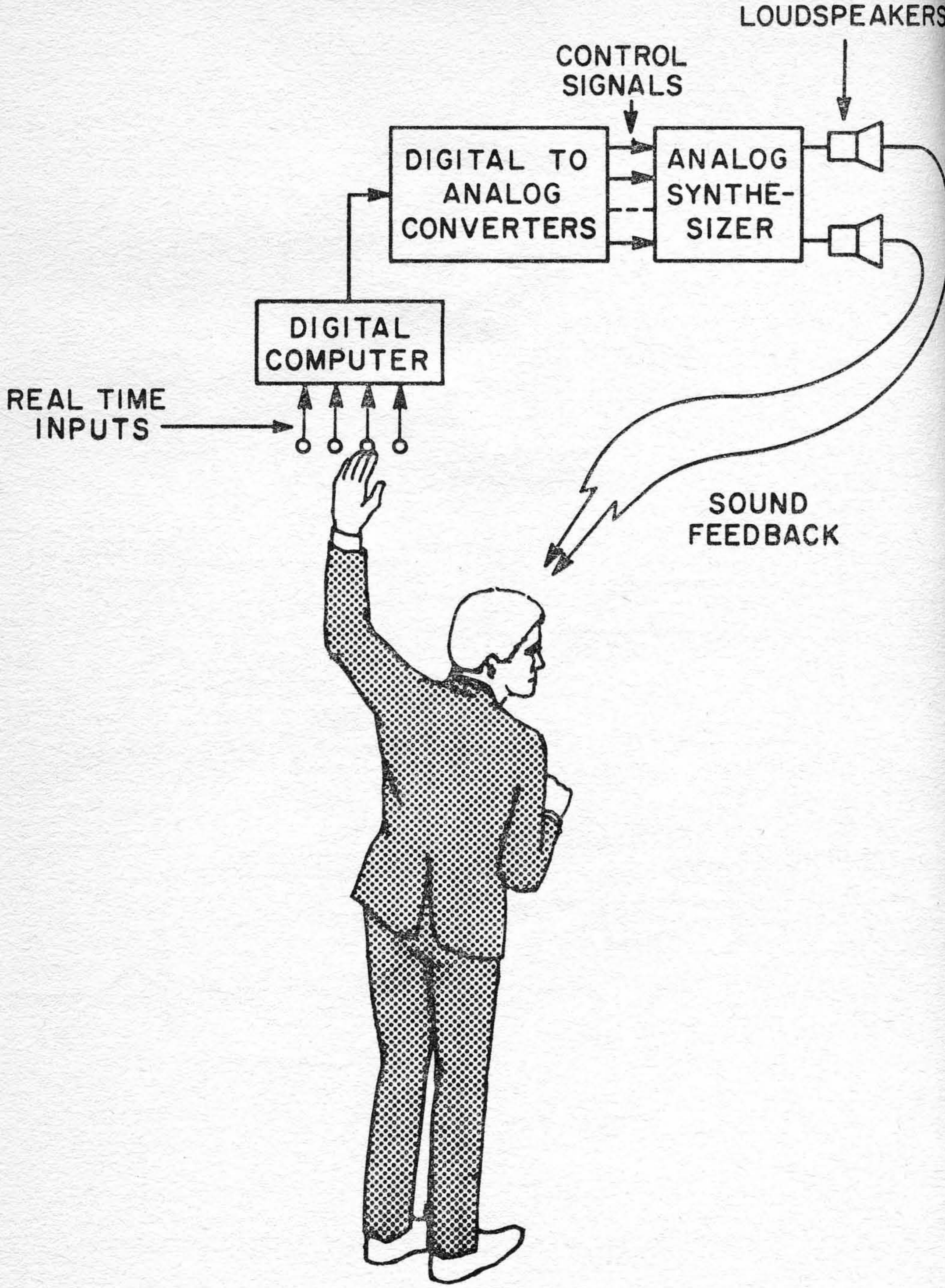

Fig. 3. *Basic structure of a hybrid sound synthesizer.*

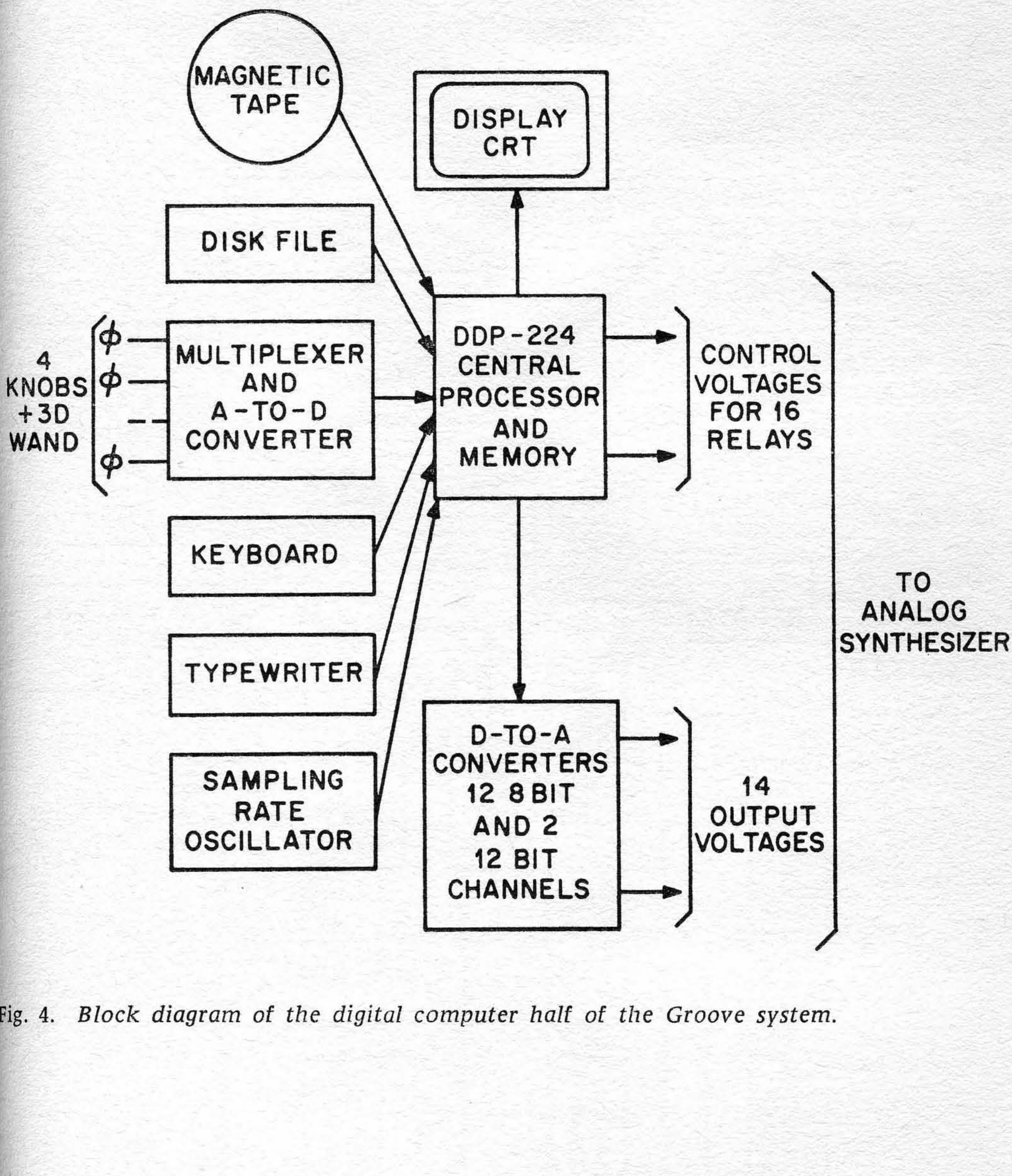

Fig. 4. *Block diagram of the digital computer half of the Groove system.*

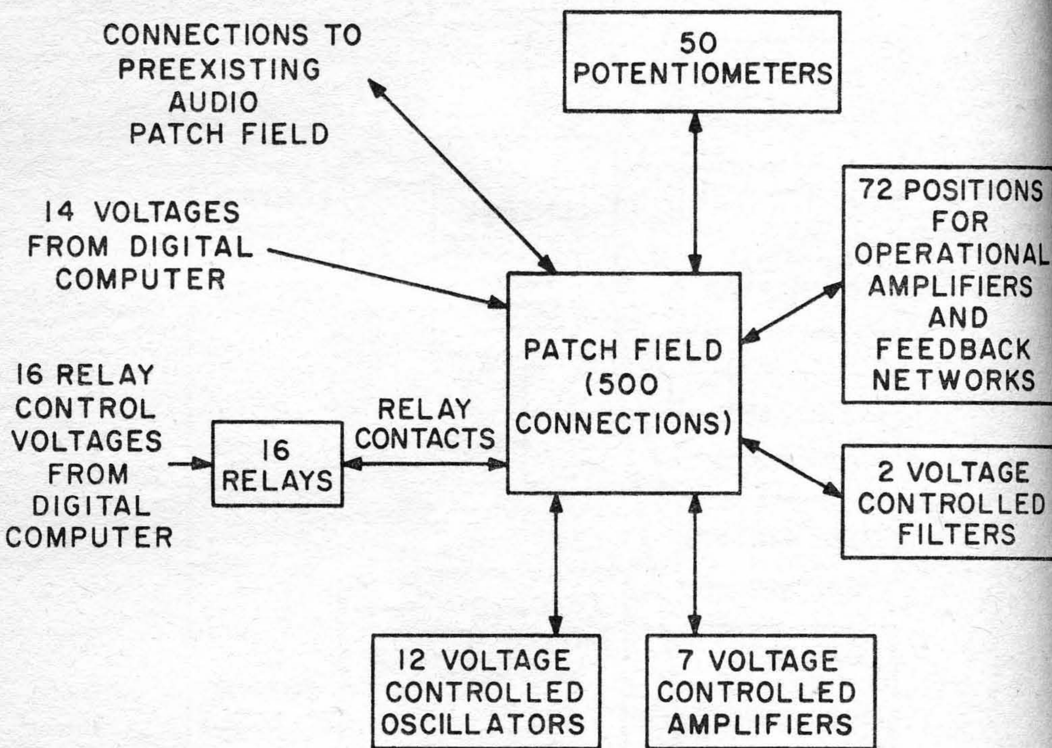

Fig. 5. *Block diagram of the analogue synthesizer half of the Groove system.*

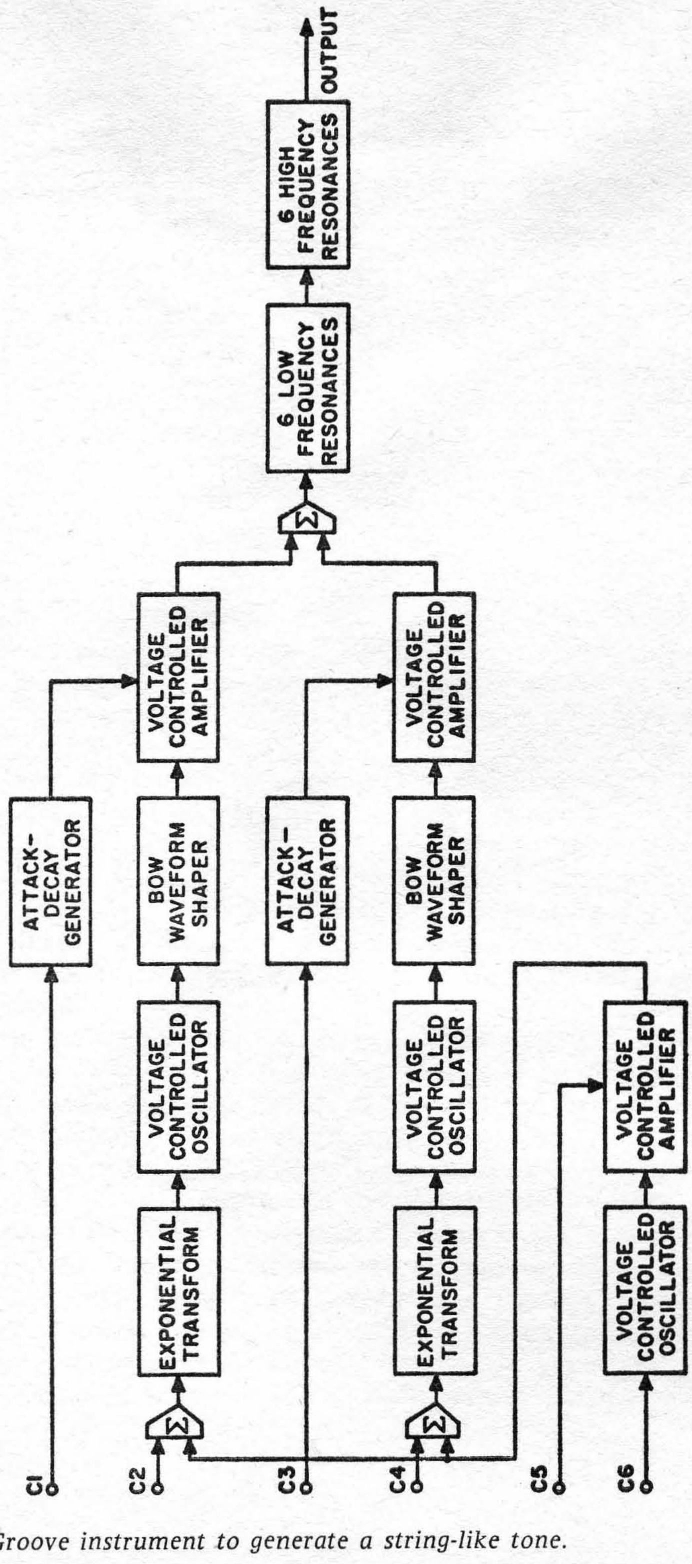

Fig. 6. *A Groove instrument to generate a string-like tone.*