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Electronic Music Synthesis

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The modern systems of communication have been applied to the electronic synthesis of music in the form of the electronic music synthesizer. The electronic music synthesizer is a machine which provides means for producing a tone with any frequency, intensity, growth, duration, decay, portamento, timbre, vibrato, and deviations. If these properties of a tone are specified, the tone can be produced by the synthesizer from a coded record. For implementing the electronic synthesis of music an improved and enlarged electronic music synthesizer Mark II has been developed and built. The new electronic music synthesizer and the use of the new synthesizer by professional musicians will be described.

INTRODUCTION

THERE are two main categories of communicating information in the form of sound waves in which the ear is the ultimate useful destination, namely, the human voice and music. The direct transmission of the original speech or music has been extended by the reproduction of sound. The reproduction of sound is the process of picking up sound in one location and reproducing at the same location or some other location either at the same time or some subsequent time. The most common sound reproducing systems are the telephone, phonograph, radio, sound motion picture, and television.

The radio, phonograph, sound motion picture, and television have made it possible for all the people of the world to hear famous statesmen, artists, actors, and musical aggregations where only a relatively small number had been able to hear them first hand. It is evident that the reproduction of sound has produced in a relatively short time a great change in the education and entertainment of this and other countries. The impact of the telephone, phonograph, radio broadcasting, sound motion pictures, and television upon the dissemination of information, art, and culture has been tremendous. The reproduction of sound in these fields has been as important to the advancement of knowledge as the printing press and the printed page.

The new systems of communication involving the processes of analysis, encoding, coding, decoding, and synthesizing are beginning to play an important part in communicating information in all forms. In this paper the main consideration will be that of the application of new elements and systems of communication to the production of music.

PRODUCTION OF MUSIC

Music is both an art and a science. In scientific terms, music is the art of producing pleasing, expressive, or intelligible combinations of tones. The sounds of original music are produced by the human voice or by an instrument actuated by a musician. Most music is recorded and translated into sounds by means of a symbolic notation on paper. The ultimate objective destination of all musical sounds is the human ear. Thus, the production of music consists of the following processes: the symbolic notation upon paper by the composer, the

* Associated with the RCA Laboratories during the electronic synthesis of music described in this paper.

translation of the symbolic notation into musical sounds by the musician employing either his own voice or a musical instrument or both, and the actuation of the human hearing mechanism by the musical sounds. The medium of transmission from the musician and musical instrument to the listener is sound waves. These sound waves carry the musical tones. The properties of a musical tone will be described in the section which follows.

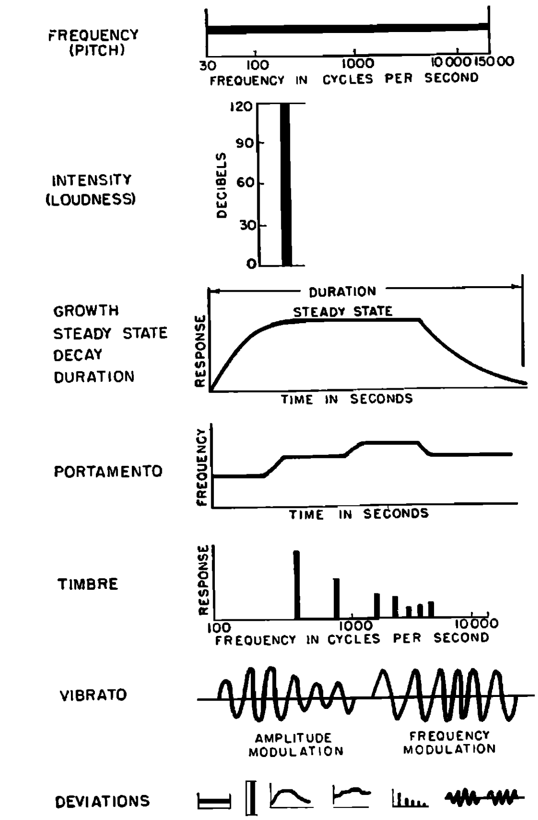


FIG. 1. The characteristics of a tone.

PROPERTIES OF A TONE AND ELECTRONIC SYNTHESIS OF MUSIC

The properties of a musical tone are frequency (pitch), intensity (loudness), growth, duration, decay, portamento (frequency glide), timbre (waveform), and vibrato. There are in addition, in some instances, various deviations in these characteristics. These characteristics of a tone are depicted in graphical form in Fig. 1. The definition and relation of these terms to the electronic synthesis of music have been outlined in detail in a previous publication.[1]

An electronic music synthesizer was developed and built based upon the production of tones in terms of the fundamental properties of a tone as outlined above. The electronic music synthesizer has been described in detail in reference 1. In this connection, an improved model of the electronic music synthesizer termed the Mark II has been developed and built. It is the purpose

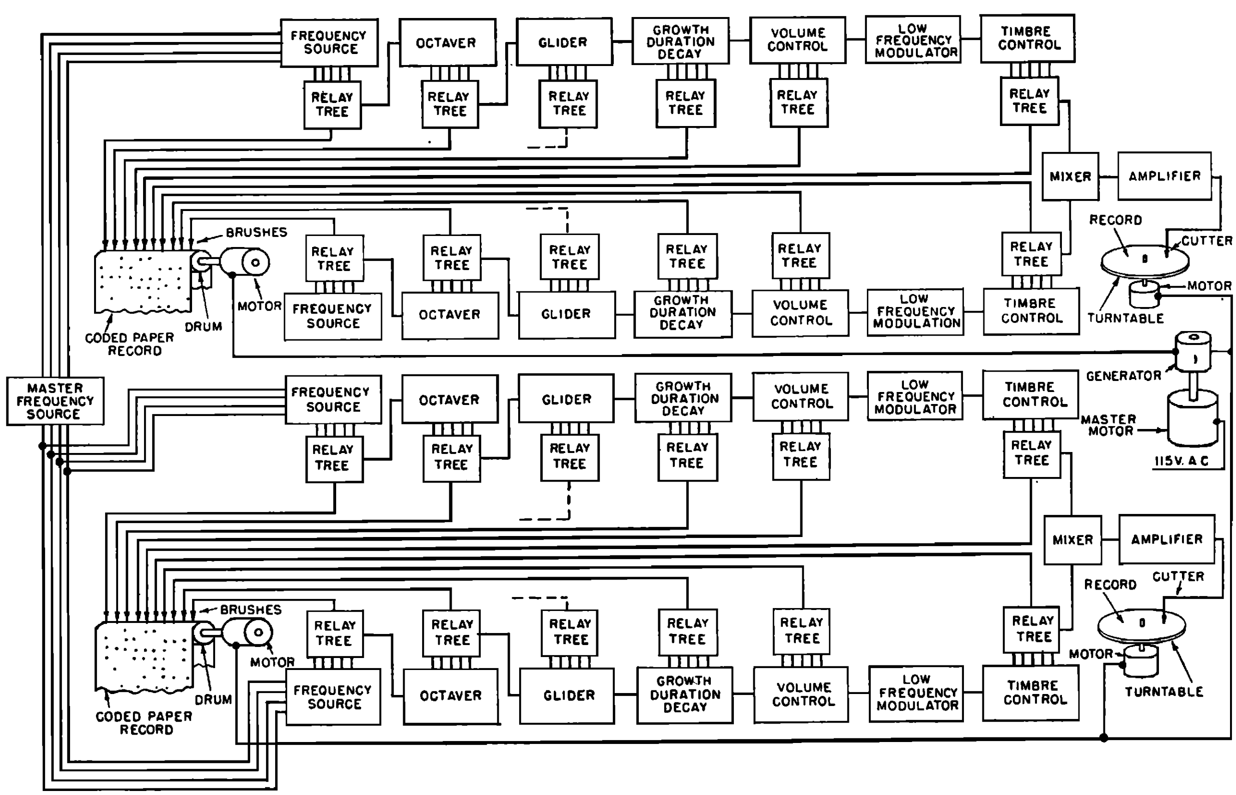
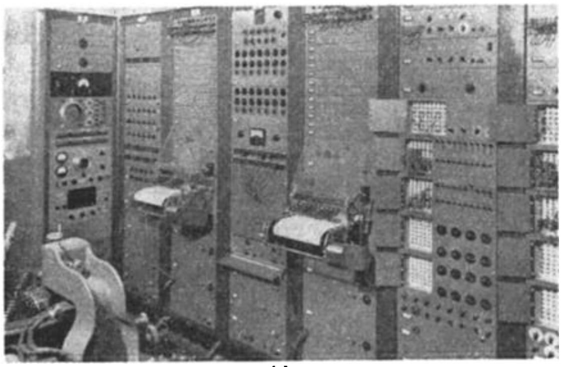
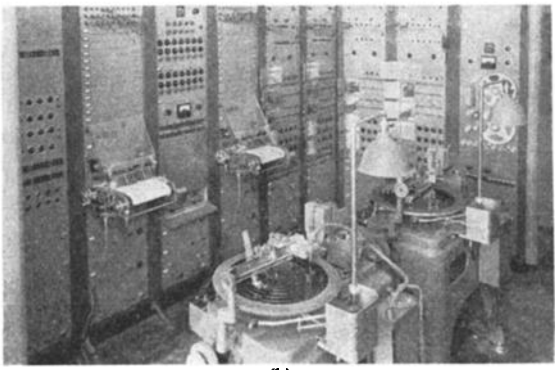


FIG. 2. Schematic block diagram of the electronic music synthesizer Mark II.

[1] H. F. Olson and H. Belar, J. Acoust. Soc. Am. 27, 595–612 (1955).



(a)



(b)

FIG. 3. Electronic music synthesizer Mark II.

of the section which follows to describe electronic music synthesizer Mark II.

ELECTRONIC MUSIC SYNTHESIZER MARK II

A schematic block diagram of the complete electronic music synthesizer Mark II with means for producing all the characteristics of a musical tone, as outlined in the preceding section and depicted in Fig. 1, is shown in Fig. 2. Photographs of the electronic music synthesizer Mark II are shown in Figs. 3(a) and (b). Referring to Fig. 2, it will be seen that there are four complete channels, two paper records, and two recording turntables. Employing four complete channels makes it possible to record four series of tones at one time. The two paper records and the two recording turntables are electrically and mechanically interlocked through the motors and generator driven from a master motor which insures absolute synchronism between the paper records and the recording turntables.

In order to simplify the operation of the electronic music synthesizer and reduce the number of rows of holes in the paper record, a binary code system is used for all the operations employing the paper record. Relay trees are used for the binary conversion system. The relay tree systems used in the electronic music synthesizer are shown in Fig. 4. Using four rows of holes in the paper record, it is possible to select sixteen different operations.

The sound sources for the master frequency source

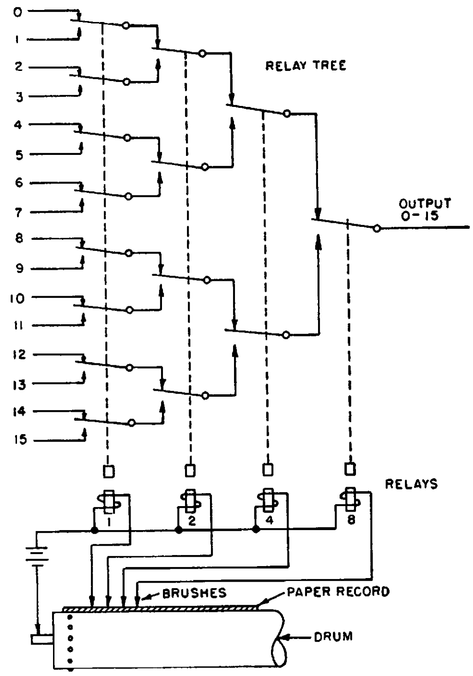


FIG. 4. Binary conversion system consisting of the paper drum, paper record, brushes, and relay tree.

consist of twelve fixed frequency, tuning fork controlled, vacuum tube oscillators tuned to the frequencies in one octave of the equally tempered scale and associated

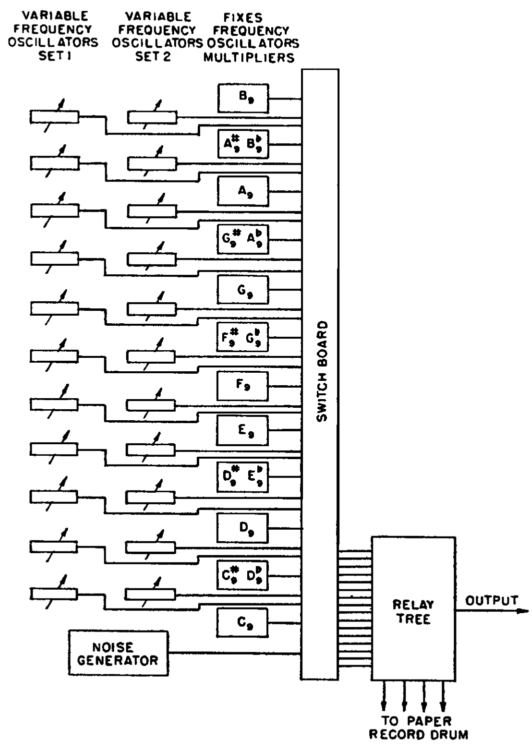


FIG. 5. Schematic block diagram of the fundamental frequency source consisting of the variable and fixed oscillators, switchboard, and relay tree.

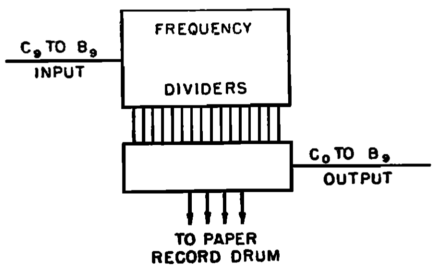


FIG. 6. Schematic block diagram of the octaver consisting of the frequency divider and relay tree.

scale of four multipliers. There are also two sets of twelve variable frequency oscillators and a noise generator, as shown in Fig. 5. The twelve fixed frequency sources make it possible to operate in the equally tempered scale. The use of the two sets of twelve variable frequency oscillators makes it possible to use the just scale as well as any other scale by pretuning the variable frequency oscillators to the desired frequency. For example, all three sets of oscillators can be used to set up a micro-scale of up to 36 tones to the octave. Still finer graduations are possible by retuning between separate takes. The tunable oscillators also permit the use of any arbitrary reference frequency instead of the standard A-440. The random noise source is useful in providing a large number of various effects in the percussion categories.

The fundamental frequency sources provide the tones in one octave. The octaver depicted in Fig. 6 consists of frequency dividers for providing frequencies from C_0 to B_9, inclusive. The combination of the system of Figs. 5 and 6 makes it possible to select any frequency in the range from C_0 to B_9, a total of 120 separate frequencies by means of eight circuits, eight brushes, and eight rows of holes in the paper record. This shows the advantage of a binary coding system in reducing the number of rows of punched holes required in the paper record. For example, in the eighty-eight note player piano, eighty-eight rows of holes in the paper record are used to select the frequency.

A block diagram of a frequency glide system is shown in Fig. 7. When the input frequency is suddenly changed from one frequency to another frequency, the output glides in frequency in a continuous manner from one frequency to the other in the following manner. The incoming signal is amplified and converted into a series of negative pulses. The pulses are sent through an integrator and a low pass filter. The resultant direct current is amplified and fed to an oscillator in which the frequency is a function of the direct current input. The output is fed to an amplifier and pulse generator. The output of the pulse generator is opposite to that of the pulse of the incoming signal. The system is a comparison system in which the frequency of the oscillator adjusts itself to the input frequency. If the input frequency changes from one frequency to a different frequency in a discontinuous step, the direct current oscillator changes from this frequency to the new frequency in a continuous manner. The comparison system can be adjusted so that the glide is accomplished in a smooth transition or in a series of approximations by the amount of amplification between the oscillator and the second pulse generator.

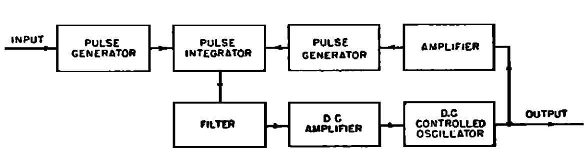


FIG. 7. Schematic block diagram of the frequency glider.

The glide system will execute a single type of glide without any outside control. However, if it is desired to have the glide change in any part of a musical selection being synthesized, the changes may be controlled by

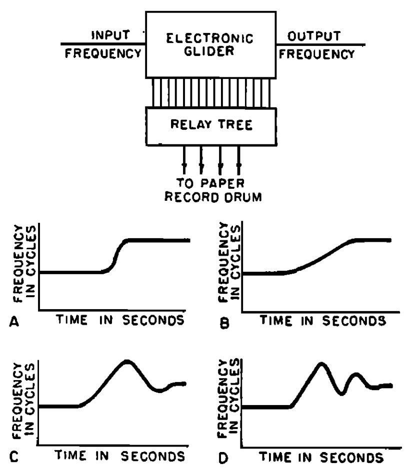


FIG. 8. Schematic block diagram of the electronic glider, relay tree, and typical frequency glides.

means of a relay tree actuated by contacts and a row of holes, as shown in Fig. 8.

A few typical glides are shown in Fig. 8. The frequency glide of Fig. 8(A) depicts a relatively rapid and smooth transition from one frequency to another frequency. The frequency glide of Fig. 8(B) depicts a relatively slow and smooth transition from one frequency to another frequency. The frequency glides of 8(C) and (D) show that the second frequency is approached in a series of approximations.

Normally the glider is not connected to a paper record drum, (Fig. 2). However, it is possible to use four circuits in the coding system and thereby provide sixteen different glides from a preset condition. Of course, an infinite number of glides are possible in presetting the system of Figs. 7 and 8.

Means are also provided in the frequency glider to flatten or sharpen its output by about $\frac{1}{6}$ tone under the control of the paper record. This is useful when the glide itself should be relatively rapid but the final approach to the exact frequency very slow. This facility has also been used to generate micro-scales.

An electronic system is used for the growth, duration, and decay characteristics. The block diagram of Fig. 9 shows that it is possible to obtain sixteen different growth, duration, or decay characteristics from a preset condition. Of course, it is possible to obtain an infinite number of preset growth, duration, and decay characteristics in the system of Fig. 9. In an electronic system it is possible to obtain growth and decay characteristics which are exponential functions as well as all manner of other functions. A few of the typical growth and decay patterns are shown in Fig. 9. The graph A of Fig. 9 depicts a growth and decay characteristic described by exponential functions. The growth and decay are moderate with respect to time. The graph B of Fig. 9 depicts a very rapid growth characteristic. The decay characteristic is an exponential function with a sudden

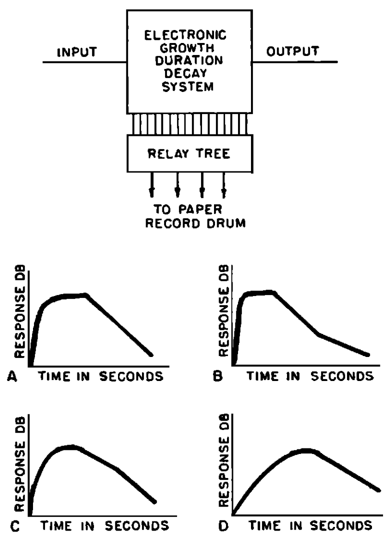


FIG. 9. Schematic block diagram of the electronic growth, duration, and decay system and relay tree and typical growth, duration, and decay characteristics.

decrease in the decay rate during the decay period. The graph C of Fig. 9 depicts discrete changes in both the growth and decay characteristics during the growth and decay cycles. The graph D of Fig. 9 depicts relatively long growth and decay characteristics.

The growth, duration, and decay system performs a double function, namely, it opens and closes the synthesizer channel and controls the growth, duration, and decay. That is, all the elements of a synthesizer channel are established before the system is unblocked by the growth system.

An electronic system is used for the volume control system depicted in the block diagram of Fig. 10. The amplification of a pentagrid converter tube with variable transconductance is a function of the bias voltage applied to the control grid. The control voltage is supplied by the relay tree from a direct current power supply. Typical input *vs* output characteristics are shown in Fig. 10(A). Controls are provided for preset-

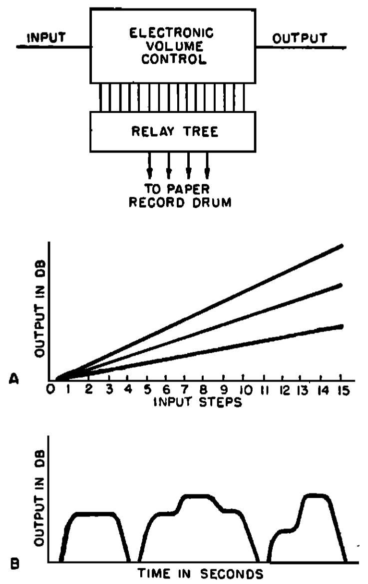


FIG. 10. Schematic block diagram of the electronic volume control system and relay tree and typical input *vs* output characteristics and the output *vs* time characteristics.

ting the over-all volume range. A few of the typical output *vs* time characteristics are shown in Fig. 10(B). As these characteristics show, the volume may remain constant or may vary during the sounding of a tone.

A low frequency modulator is provided as shown in Fig. 2 for producing a vibrato or tremolo. The modulation frequency may be varied over the frequency range of from 5 to 10 cycles per sec.

The output of the octaver produces a saw tooth wave which contains the fundamental and all the overtones. The spectrum of a saw tooth wave having a fundamental frequency of 440 cycles is shown in Fig. 11. The timbre control system shown in Fig. 12 employing filters and resonator chains provides a means for changing the timbre or overtone structure. Practically any overtone structure whatsoever may be obtained by means of the frequency discriminating systems employed in the timbre control system. A few typical examples of the overtone structures which may be obtained by the timbre control system are shown in Fig. 12.

The paper record is punched by means of the key-

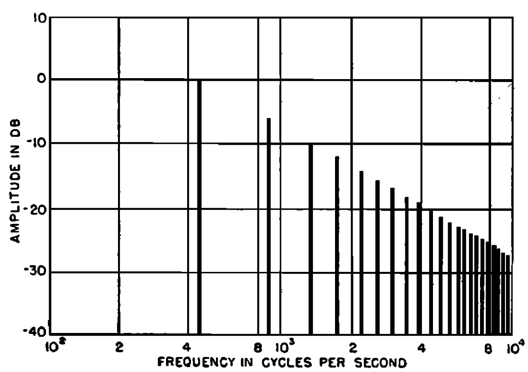


FIG. 11. The frequency spectrum of a saw tooth wave with a fundamental frequency of 440 cycles per sec.

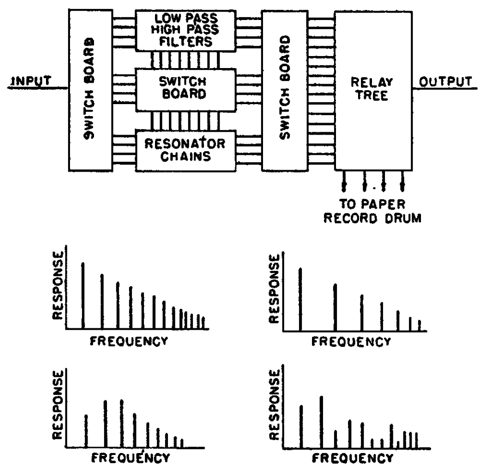


FIG. 12. Schematic block diagram of the timbre control system consisting of switchboards, low and high pass filters, resonator chains, and relay tree.

board punching system shown in Fig. 13. The keys are colored to facilitate the operation of punching the codes. The note-selecting group of 1, 2, 4, and 8 are red. The octave group is yellow. The growth, duration, and decay group is blue. The timbre group is gray. The volume control group is black.

Referring to Fig. 13, it will be seen that the punched record consists of rows of holes. Each row of holes passes under a brush. When the brush passes over a hole, the brush makes contact with the drum, and as a result closes the actuating circuit in the relay tree. Each brush is equipped with several springs arranged so that the brush never breaks contact with the drum before making contact at the adjacent hole. Thus, a row of holes will provide continuous contact and at the same time give the same result as a slot in the paper. Slots cut in the paper will results in a very weak record that can be easily torn and with poor lateral rigidity.

A simple punched record for playing a phrase of "Obelin" is shown in Fig. 14. The record is drawn to scale and has the length indicated in inches. A paper

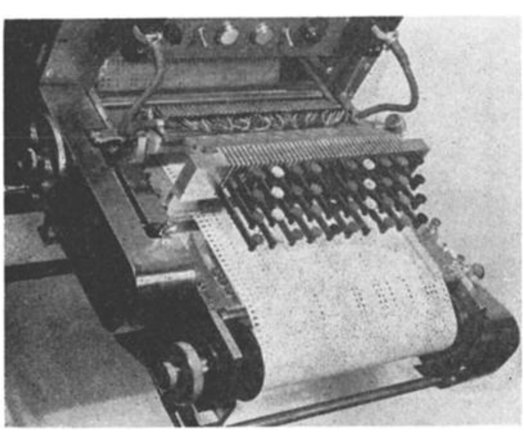


FIG. 13. The keyboard punching system.

speed of 4 in. per sec was chosen for this selection. The corresponding measures in conventional musical notation are also shown in Fig. 14. The rows of holes are numbered like the keys of Fig. 13 in the binary code numbering. Referring to Fig. 14, it will be seen that the coding of the left half is for one synthesizer channel and the coding on the right for the other synthesizer channel. Referring to the growth, duration, and decay coding, it will be seen that the notes are executed alternately by the first and second channel. Figure 14 shows the changes in growth, decay, and volume which are the synthesist's interpretation of this musical selection as called for in detail by the coded information shown below the conventional music notation.

When the two paper records have been punched and the settings of the various elements of the synthesizer have been established, the next step is the recording of the output of the synthesizer. The two disk phonograph recorders are shown in Figs. 2 and 3.

The synthesizer is purposely limited to the production of four simultaneous tones. The reason will be evident in the description which follows. In general, because of the buildup and decay characteristics of most musical sounds, the system is actually limited to two musical tones. That is, each coded paper record can produce a musical sequence of tones. Thus, it will be seen that if more than two musical tones are required that some means must be provided for combining a large number of musical tones which are sounded simultaneously. The sixteen-inch disk record can accommodate six three-minute records. After six complete recordings have been made, the six recordings of one record can be combined into a single recording by means of the two turntables and the arrangement shown in Fig. 15.

The two turntables are electrically and mechanically interlocked through the motors and generator driven from a master motor which insures absolute synchronism between the two turntables. The record containing the six programs is reproduced by means of six pickups and the output of the pickups fed to a mixer amplifier. The mixer provides means for adjusting the balance among the six recordings. The output of mixer amplifier is fed to the recording amplifier. The output of the recording amplifier is fed to the cutter. In this way six original records can be combined into one record. This process can be carried on and practically any number of musical tones can be combined.

The final complete selection is recorded on magnetic tape. If there are twelve or less musical tones the two records can be reproduced from the two turntables and recorded on magnetic tape without any additional disk recording process.

PRODUCTION OF MUSIC BY MEANS OF ELECTRONIC MUSIC SYNTHESIZER

The electronic music synthesizer described in the proceding section provides means for producing all the characteristics of a tone: namely, frequency, intensity,

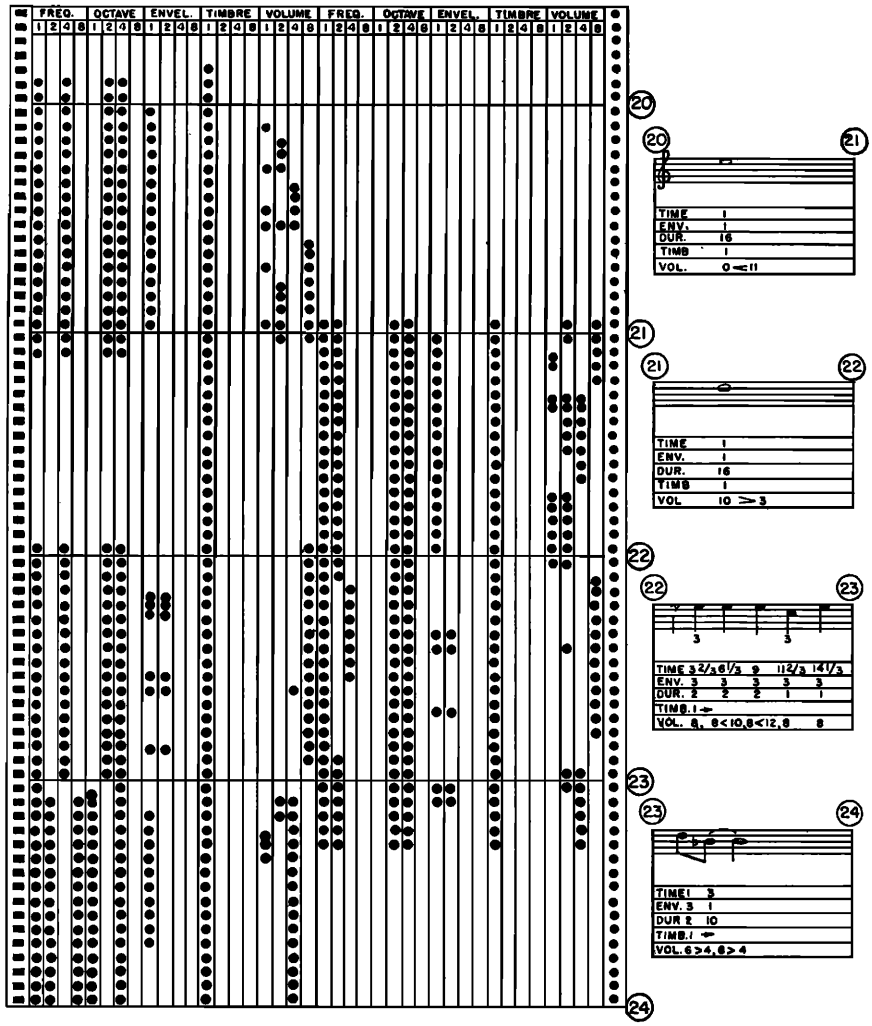


FIG. 14. A copy of the paper record containing a phrase of "Obelin".

growth, duration, decay, frequency glide, waveform, and vibrato. When the synthesizer is used by musicians, these are the characteristics of the tone which must be specified. At first glance it would appear that the use of the electronic music synthesizer for the production of music would be a very complex and cumbersome process. On the contrary, the use of the synthesizer is a simple and straightforward procedure. It is the purpose of this section to describe the production of recorded music from a musical score by means of the electronic music synthesizer.

The first step in the electronic synthesis of music is the evolution of the musical score by the composer or arranger. The composer or arranger determines the various tone structures which will be employed to produce the first product. He writes the musical score for each of these series of tones. The musical score carries the specific information on the scale, frequency, and duration of the tone. The musician indicates on the musical score the growth and decay and the timbre. He also indicates glides and vibrato if these are used. When the musical score with the specific notations has been completed, as shown in Fig. 16, the next step is the transfer from the musical score to the code.

Any musical score is itself a coded presentation of the composer's work which, before it can become music, requires further interpretation. Many factors including

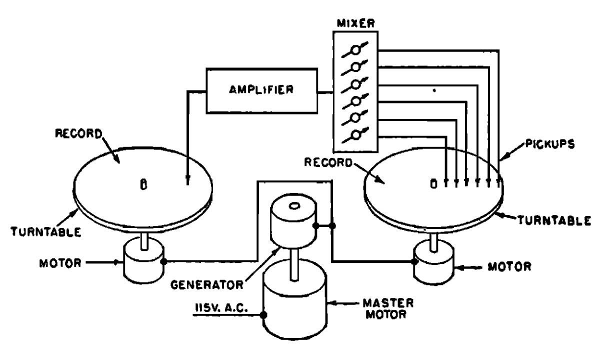


FIG. 15. A schematic diagram of a system consisting of two synchronized turntables, records, pickups, mixer, amplifier, and cutter for combining several recordings into one recording.

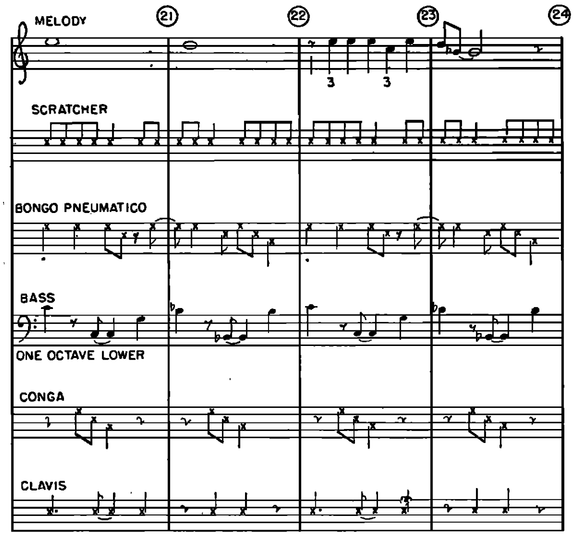


FIG. 16. Excerpt from musical score for "Obelin" composed by Jim Timmens.

artistic considerations enter into the problem of interpretation making this the most difficult part of synthesis, but also the most rewarding from the viewpoint of the unlimited possibilities offered. Once the interpretation is made, the rest of the work can be done systematically as will be shown. Returning to the example, of which score an excerpt is shown in Fig. 16, it was decided to synthesize a rhythm section in the Latin American style which would sound plausible, but not a copy of any existing instrument exactly.[2] The aim was to perform an experiment in creating music which would be commerical in today's market, not too different yet still possessing novelty. Before the score had been completed experiments were made with short sections trying different envelopes of sounds in the percussion category, that is, envelopes with rapid growth followed immediately by a period of decay. After selecting resonators and filters which gave the desired result, the next task was the determination of an envelope normally associated with a lip reed instrument but still using the sound source and timbre quality selected for the percussive sound. The result is a nonexistent instrument which was dubbed Bongo Pneumatico. The resultant sound suited the genre of the selection; so it was decided to use it. Having established in similar manner various other interpretations, a schedule was made showing the general classification of the sound categories by which the score was interpreted. The classification schedule is depicted in Fig. 17. The number of setups and parts are determined from the schedule of Fig. 17. The procedure is carried out by considering the number of different sounds which must appear simultaneously in the finished selection and the resultant setups required. The organization of the parts for the sample selection is shown in Fig. 18. The writing of the individual parts is the next step.

	RAPID GROWTH	SLOW GROWTH	VARIOUS GROWTH	IMMEDIATE DECAY (LOG.)	VARIOUS DECAYS	NOISE SOURCES	FREQUENCY SOURCES	RESONATORS	FILTERS	FREQUENCY GLIDERS
CLAVIS	x			x		x		x		
CONGA	x			x		x		x		
BONGO	x			x		x		x		
BONGO PNEUMATICO		x			x	x		x		
BELL	x				x		x		x	
BASS	x			x			x		x	
SCRATCHER			x		x	x		x		
PLUCKED STRINGS	x			x			x		x	
MELODY			x		x		x		x	x

FIG. 17. General classification of nine sound categories called for in the musical score for "Obelin" by Jim Timmens as arranged for the electronic music synthesizer.

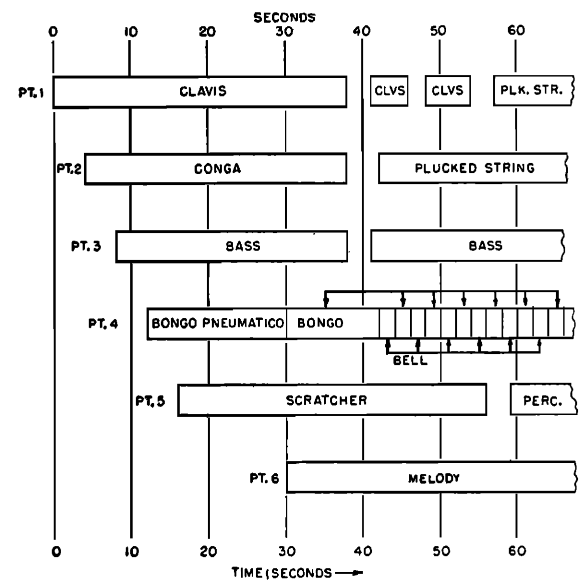


FIG. 18. Organization of the parts for "Obelin."

Techniques were developed to set forth the specifications in both conventional musical and coded technical terms. The latter includes the desired interpretation and follows in a more detailed manner the precept of the performance score developed by Carl E. Seashore.[3] Figure 19 shows page one for part 6 which carries the melody for "Obelin."

Referring to Fig. 19, the bars denoting the measures in conventional notation are numbered. The distance between bars represents 16 rows of holes in the paper

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

[3] C. E. Seashore, *Psychology of Music* (McGraw-Hill Book Company, Inc., New York, 1938).

record into which the information is to be punched. At a paper speed of 4 in. per sec and with a normal hole spacing of four to the inch, this means 16 holes per sec will pass under the brushes in the playing of this part. The normal length for a quarter note is then four holes or one inch in order to play at a metronome speed of 240 quarter notes to the minute. The time at which the growth of a note is to begin is interpreted in the first tabulation under the staff. Thus, any deviation desired can be specified. The next code specified is the envelope. In the example given, it was decided that this part should be of sustained tones capable of being varied in loudness during the sounding of a note and have different degrees of attack. Accordingly, a setup was made providing for different rates of growth according to the number called for in the schedule. The decay inherent in the instrument was arranged to be always about the same in time constant but the duration between growth and decay was made unlimited. The duration itself was specified in the third row of the code tabulation. It may be noted that the duration of similar notes is not always specified to be of the same length. These deviations are one of the aspects of interpretation.

For the duration of the four measures shown in Fig. 19, the timbre was the same and specified as code 1. The actual timbre for that portion was produced with a harmonic spectrum containing all harmonics diminishing with their order but with the higher orders reduced more drastically. The last tabulation of codes concerns volume. The volume is nearly always changing as it would with a lip reed or bowed instrument with some expression.

Figure 14 shows how the directions outlined on the part of Fig. 18 were carried out in punching out the paper tape record. Time now becomes a longitudinal dimension measured in inches or in holes. The frequency of each note is determined directly from the music notation which is easily learned. The only difference between the notation and the suggested "American Standard for Subscripts"[4] is that in order to make all relay trees have the same numbering, $C_0 = 16.352$ cycles is denoted by C_1; but since octaves can be switched at will manually, this is no great handicap.

Others parts than the one shown were produced in similar order and finally all recorded on different bands of a 16-in. lacquer record. Reverberation was then programmed for the parts selected, final adjustments were made, and the overall combined on tape. Copies of the tape record have been demonstrated to many audiences both in Princeton and during various talks given on RCA Laboratories activities all over the country and have received many favorable comments.

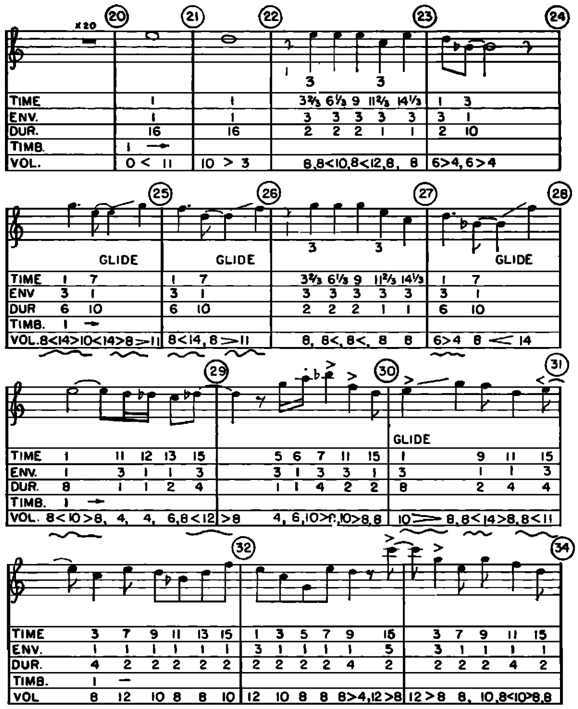


FIG. 19. Synthesizer code sheet for Part 6, page 1, of "Obelin". MM: quarter note = 240.

ACKNOWLEDGMENTS

Acknowledgments are due many who contributed to the work described during the time covered in this paper. Richard Maltby, the well-known band leader and recording artist then with RCA Victor, contributed original compositions and arrangements; Mr. R. A. Lynn followed the design and construction of the Mark II electronic music synthesizer; L. Butterfoss did much of the construction; and G. M. Schmelz, much of the encoding.

[4] H. F. Olson, *Musical Engineering* (McGraw-Hill Book Company, Inc., New York, 1952).