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THE TECHNICAL FACILITIES OF THE ELECTRONIC MUSIC STUDIO [OF THE COLOGNE BROADCASTING STATION]

BY

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THE TECHNICAL FACILITIES OF THE ELECTRONIC MUSIC STUDIO [OF THE COLOGNE BROADCASTING STATION]

Summary

This article describes the technical equipment of the electronic music studio in the Cologne Broadcasting Station. An outline is given of the most important considerations, starting from the basic principles, and the methods and apparatus used are described in greater detail. The equipment consists chiefly of electronic tone and noise sources, electro-acoustical shaping devices and sound-recording apparatus.

In every period of history musical instruments have been built with whatever means were available. It is only natural, therefore, that electronics, which is being applied everywhere, should now be employed for this purpose. To the electro-acoustics engineer this opens up a new and fascinating field of activity in which the following applications are involved:

1. Electronic imitation of acoustic musical instruments (electric imitators).
2. The production of acoustic effects by electronic denaturation of the acoustic phenomena (concrete music).
3. The production by electronic means, in accordance with a preconceived plan, of musical sounds which cannot be produced mechanically (electronic music)[1].

The work of the Cologne Studio is devoted primarily to the fields of electronic and concrete music. It is obvious that the production of sound effects for radio plays will be included in this program.

Since this was the first project of its kind there was no experience on which the studio designers could draw. It must therefore be expected that many of the means employed would not be successful in practice.

In order to fulfil the purposes for which the studio was set up the following technical equipment was necessary:

(a) Electronic sound and noise-producing sources to provide the raw material for further processing.

(b) Electro-acoustic shaping means for the purpose of influencing the tone frequency spectra and the transient processes of sound phenomena. The methods used here are taken from communications technique and yield sound phenomena which cannot be procured by mechanical methods.

(c) Magnetic sound-recording apparatuses for further processing of the material obtained with devices a and b.

These means make it possible for a composer to set down his works exactly in accordance with his conceptions and to have it heard without the aid of interpreters (director and orchestra).

The relationships between the important parts of the equipment are shown diagramatically in Fig. 1.

A. The Electronic Sound and Noise Producers

Electronic sound producers make it possible to produce musical sounds far surpassing our imagination, which is oriented to conventional mechanical musical instruments. The timbre is arbitrarily variable and thus is freely accessible as a new shaping element.

Among the numerous available apparatuses for these purposes an electronic monochord, a melochord, a generator of

white noise and a number of audio-frequency generators were chosen.

The electronic monochord has been developed from the Trautonium specifically for electro-acoustical purposes. The name was chosen for this instrument by analogy with the acoustic monochord*.

The harmonically rich spectra of the electronic monochord can be analysed in a great many different ways by frequency band clipping. The possibility it affords of producing any desired musical scale conveniently and independently of fixed tone intervals is regarded as particularly valuable.

In the melochord the sounds are produced by RC-generators whose frequency is determined by resistances switched on and off by means of piano keys. The timbre differs greatly from that of acoustic instruments; at the same time the transients of the sounds can be influenced**.

For the production of white noise a noise generator operating on the super-regenerative principle, as described by Kösters and Harz, is employed. The circuit noise is considerably increased by super-regeneration and is brought up to the required output voltage by means of an amplifier which also contains the anti-distortion elements. A quench frequency of approximately 140 kc./sec. is produced by the triode system of a mixture tube and combines with the high frequency forming in the hexode system. The requirement that one of the roots of the voltage be proportional to the band width (ideal white noise) can be satisfied within a range of 20 c. to 20 kc./sec. (Fig. 2).

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*A complete description will be given by F. Trautwein elsewhere in this series. (N.R.C. TT-606).

**A detailed description is given elsewhere in this series by the builder H. Bode. (N.R.C. TT-607).

The beat-frequency oscillator is especially useful in covering the entire audio-frequency range. Its voltage must of course be constant at all frequency settings except for a negligible non-linear harmonic distortion factor and an inaudible hum voltage.

In order to represent musical intervals audio-frequency generators with a comparatively large constancy of frequency are required. Commercially sold, bridge-stabilized arrangements with decadic frequency adjustment and an accuracy with respect to frequency of 10^{-3} have proved very satisfactory for this purpose.

B. The Shaping Means

1. Modulation

By multiple mixture of sounds new sound phenomena are produced which are no longer related acoustically with the raw material. For this purpose we have a ring modulator and a quadripole modulator. The ring modulator is used primarily for frequency transposition, i.e., the displacement of frequency spectra to other frequency ranges while retaining all the frequency intervals[2]. In this process the carrier and signal frequencies are suppressed without special means, whereby it is possible to obtain a cross-talk damping of at least 65 db.

The quadripole modulator[3] is of great importance. This is a special form of Graetz circuit in which four different frequency spectra of the sounds to be mixed (Fig. 3) can be obtained by means of different switch positions. These spectra differ from one another not only physically but also subjectively. The fundamentals of these spectra are represented in Fig. 4. The following processes can be achieved merely by changing the switch position: frequency band transposition, frequency band transposition and one of the output sounds,

amplitude modulation, amplitude modulation and one of the output sounds.

It should also be pointed out that with the aid of the ring modulator a sound which is rich in overtones can be transformed by superposition of a sinusoidal audio-frequency oscillation into an oscillation which is rich in overtones and contains only uneven harmonics.

2. Frequency band compression and expansion

If a sound record is played at a speed other than standard, then, depending on the extent of the change in speed, the reproduction may be changed from the subjective point of view so as to be unrecognizable. A curtailment of the time in such a case is acoustically equivalent to an expansion of the frequency band, while a lengthening of the time constitutes a contraction of the original frequency band(5). Frequency band compression and expansion can be used extensively for influencing sound records. The intervals, in this case, remain unchanged while the transient processes are subjected to a very far-reaching transformation.

By means of frequency band compression especially fine effects of this kind can be produced which, owing to the size and weight of the acoustic apparatus which would be needed, could not possibly be attained by purely mechanical means. It is also possible to create echo times of extreme length. The possibilities afforded by continuous variation of tape speeds will only be mentioned in passing. The frequency modulation obtained by rhythmic tape speed variation can often be used for frequency vibrato effects.

A fairly old, rebuilt AEG-mechanism (B-apparatus) is used for frequency band compression or expansion, the tape speed being variable between 9 cm./sec. and 120 cm./sec. in small stages.

3. Frequency band clipping

This refers to the production of restricted frequency bands from broad spectra. For this low-pass, high-pass and band-pass filters are necessary. Of the many possible applications of frequency band clipping only the two most important will be mentioned - the attainment of sounds of defined structure from saw-tooth oscillations containing many overtones and the conversion of white into coloured noise. In this way the raw material is obtained for the analytically producible sounds.

The filter problem, of course, has special importance. A thorough treatment of these questions is being undertaken by Adams elsewhere in this series. For high- low- and band-pass filters the radio drama distorter introduced by the German Broadcasting System does good service. In addition, however, a set of filters connected in parallel (Fig. 5) has been developed for the production of frequency combinations and partial note combinations. It consists of eight octave filters having consecutive pass-bands. Outputs and inputs are connected through buffer stages. The damping of each filter can be altered within the band-pass width by means of controls. To facilitate operation the set of filters is remote-controlled through pressure keys and relays.

4. Provision of rhythm

Rhythmic character is given, without restriction to the manual dexterity of an instrumentalist, by electronic means on acoustic-psychological principles. As examples of the many suitable methods two will be mentioned here.

Rhythm may easily be imposed on the musical sound structures by means of ring modulators and tape loops. Fig. 6 shows how the sequence of sounds and the audio-frequency

voltages picked up from a scanned tape loop are fed to the input terminals of the modulator. The ring modulator only passes the sound when carrier and signal frequency are applied simultaneously, but possesses considerable stop-band attenuation against individually occurring frequencies.

Now, if a series of pulses is applied to the tape loop in accordance with the desired rhythmic structure, the modulator will be blocked against the musical sound wherever the tape is free of impulses.

In this way any desired rhythmic pattern may be imposed on the sound phenomena. Particularly complicated rhythms may be produced by causing the control pulses to be reproduced at a slower speed than recorded. It is merely necessary to take care that the resulting products of modulation lie beyond the audio region. If the pulse frequency is 30 kc./sec. this requirement is satisfied. (This frequency can be produced and reproduced by the Magnetofon).

An arrangement will also be described which permits the timbre structure to be varied rhythmically with the set of octave filters. For this purpose the remote-control keys are bridged by switching circuits operated at audio frequency. There are eight of these switching circuits present, each operating an octave filter (Fig. 7). These switching circuits comprise triodes in anode rectifier arrangement, possessing a resonance circuit between the grid and the cathode and a relay to operate the filter control in the anode circuit. With this arrangement selection can be obtained over a band width of 400 c.p.s., so that eight switches can be released at frequencies between 1,000 and 5,000 c.p.s. These frequencies are recorded on a tape loop in accordance with the rhythmic requirements and on reproduction they control the selective switches.

The method of altering the rhythmic structure of magnetic tape recordings by the tape clipping technique (cutters) will be discussed elsewhere in this series.

5. Shaping of the dynamics

The useful dynamics of electronically produced sounds and noises depends on the ratio of noise voltage to useful voltage. Owing to the complicated nature of the sound-producing processes this value is never a constant. It has to be determined anew for each sound event, so that variations of the noise voltage interval of 20 db. must be reckoned with.

A sound process built up of numerous components will arouse very different feelings at different volumes. Equal volume for recording and reproduction are therefore an indispensable requirement which is best assured if the sound pressure of the loudest portion of the composition is clearly determined. For this purpose the sound pressure corresponding to this volume is measured during the recording with an octaval noise of 800 to 1600 c.p.s. All other volumes can then be measured with the tone variator and can be determined at suitable approximation in decibels below this maximum value.

The volume is governed by the controls generally used in radio with constant source resistance. Rapid dynamic structures which cannot be produced in this way are obtained by means of an electrical arrangement. This consists of two mixer hexodes whose conversion slope, and hence amplification factor, is determined by a direct current voltage fed to the second control grid, while the audio-frequency voltage is connected to the first control grid[6] (Fig. 8). The value of the direct-current voltage depends on a photoresistor which is controlled in turn by the varying density of a moving film carrying different degrees of grayness (Fig. 9). This tape comprises a white film on which the required variation of the

dynamics or any desired balancing processes can be recorded in the form of varying grayness values with the aid of a quick-drying varnish. The recording is carried out with the film at rest, the dynamics being determined independently of the tape speed with the aid of a tone variator.

6. The production of resonance

It is necessary to distinguish between three different resonance processes. If the difference in time between the direct and indirect sound is less than 50 millisec. the resonance merely results in an increase of volume. However, if the reverberation occurs later, up to 100 millisec., then a blurring of the original sound becomes evident. All reflections which return after a time greater than 100 millisec. are separated from the original and heard as an echo(7).

As far as studio problems are concerned, the latter two cases are of general significance. If we wish to furnish a sound process with a reverberation up to and beyond the blur threshold, we can do so with the aid of the hall used for radio drama purposes. However, if it is necessary to separate the original sound from the reverberation by a considerable interval, it is advisable to use the regenerative Magnetofon. The process depends on the time interval between recording and reproduction, which depends in turn on the distance between the recording head and the pickup head. The reproduction attenuator is connected via a control to the recording amplifier, so that the reproduction voltage is recorded again after a certain interval (Fig. 10).

C. Sound Recording

The sound structures of electronic music comprise numerous layers which are produced singly by electro-acoustic means and are then combined. Using a Magnetofon with four

tracks, the recording of several layers independently becomes possible. Each of these four layers can be altered or erased without affecting the others. After completion, all the tracks can be replayed together on a normal Magnetofon. This apparatus, which is constructed for 17.5 mm. magnetic film perforated on one side, drives two tape players simultaneously with a single drive mechanism. Each tape possesses two tracks 3 mm. wide and 4 mm. apart (Fig. 11).

The cross-talk transmission equivalent from track to track is greater than 50 db., while the noise voltage interval, which of course is less than for the normal track, is 54 db. Any effect on the signal-to-noise ratio during erasure of the adjacent track is avoided by disconnecting the unused erasing head. The comparatively long full-speed running time of about 10 sec. should be taken into account during the recording. The four-track magnetic tape apparatus can be manipulated so that the material on three recorded tracks is transferred to the fourth, the three tracks then being erased can have new material recorded on them, so that in this way any number of layers can be combined. Synchronization of all the recordings is assured by the perforations and a common drive mechanism.

D. Spatial Arrangement of the Apparatus

Sound recordings of electronic music can be presented to the public in the concert hall or over the radio in the homes of the listeners. Whereas narrow limits are imposed on the spatial representation by the single channel radio-transmission, in the concert hall the space coordinates can be taken into account in the composition plan. The arrangements of our studio, in combination with the monitoring and soloist loudspeakers of the large transmission studio, can be used to good advantage for this purpose. The 18 loudspeakers along the sides and ends of the studio are divided into three

separate groups (Fig. 12), each being connected to one reproducing channel of the four-track Magnetofon.

In this way an arrangement of three sound sources in space is obtained. The modulation of the fourth track can be imposed through control amplifiers with the aid of the frequency controlled switches depicted in Fig. 7 and a prepared tape loop, as desired on each of the loudspeaker groups. If apparent distance and volume of the sound sources are changed at the recording stage on the tape by electro-acoustic means, e.g. frequency band clipping and resonance, a considerable increase in the emotional response evoked by the sound constructions can be attained.

E. The Analysis of Sounds

The presentation and reproduction of sounds and noises is greatly facilitated by their clear characterization. A knowledge of the frequency spectra is useful for this purpose, along with a description of the way in which the sounds are produced. Therefore, the determination of the spectral composition of sound phenomena forms a regular part of the problems which arise. This demands great resolving power.

Among the numerous measuring processes only the beat-note method is employed. The considerable time required for this can be gained because every non-steady process can be transformed into a steady one with the aid of tape loops.

A ring modulator in combination with a reflecting galvanometer having a build-up time of 1 sec. and hence a resolving power of 1 c.p.s. (Fig. 13) proves very useful here. This arrangement yields very high selectivity up to a fraction of a c.p.s.[8].

F. Arrangement of the Circuits

It was considered important to have all the switching processes as simple as possible so that operation would come easily on short acquaintance even to a person with only a small amount of training. Thus the most important apparatuses and controls are placed so that they can be manipulated from one position (Fig. 14).

The parts of the apparatus which cannot be brought within reach of this position are remote-controlled. Thus operation is reduced essentially to the pressing of keys. The required circuits are then closed by means of suitably connected relays, each switching operation controlling a number of different processes. A special key is provided for each process and its activation initiates the required circuit connection.

The modulation diagram is shown in Fig. 15. All sound and noise sources can be connected to the four-track Magnetofon by means of a relay-controlled cross-bar distributor through the shaping means. In addition to the generators already described, one arbitrary source, one Magnetofon for sound reproduction and one electronic timemarker can be added. The latter, which performs the function of an electro-acoustic metronome, is used to provide time marks on the magnetic tape.

To facilitate operation, the set of octave filters is remote-controlled through pressure keys. For this purpose the grid bias controlling the separator stages is lowered.

It should also be mentioned, that every nodal point on the circuit network can be monitored through selective switches.

A cathode-ray oscillograph is used for measuring frequencies with the aid of Lissajous diagrams. The four-track

Magentofon is also operated from the control position. Forward run and reverse, as well as the recording amplifier, are remote-controlled.

Cooperation with the other working areas of the radio station is insured by cross-connections through the main switch room. This includes connections to the general controlling and light signal installations.

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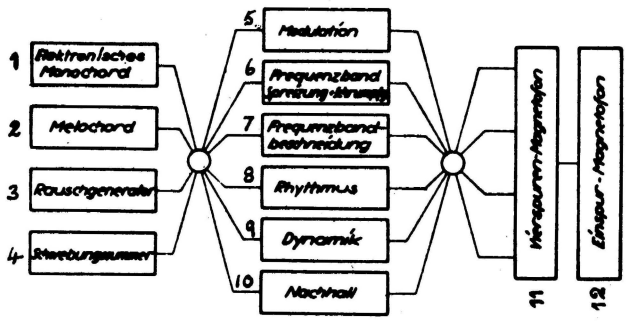

Fig. 1

Block diagram for the electronic music studio.

Elektronisches monochord	= Electronic monochord	Frequenzband beschneidung	= Frequency band clipping
Rauschgenerator	= Noise generator	Rhythmus	= Rhythm
Schwebungssummer	= Beat-frequency oscillator	Dynamik	= Dynamics
Frequenzband Spreizung + Schrumpfg	= Frequency band compression and expansion	Nachhall	= Resonance
		Vierspuren-Magnetofon	= Four-track Magnetofon
		Einspur-Magnetofon	= Single track Magnetofon

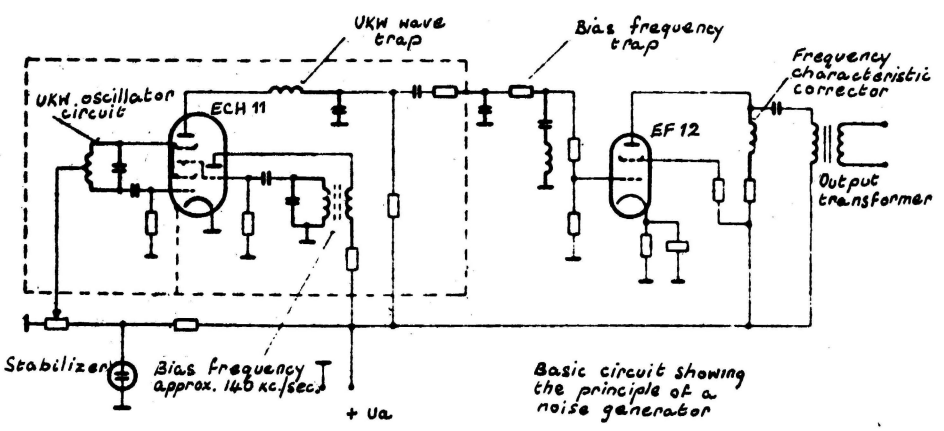

Fig. 2

The circuit of a noise generator

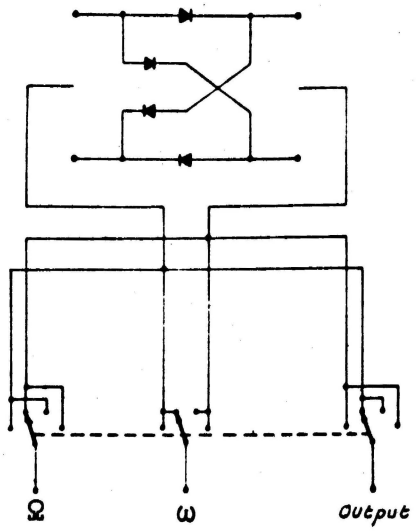

Fig. 3
Variable quadripole modulator.

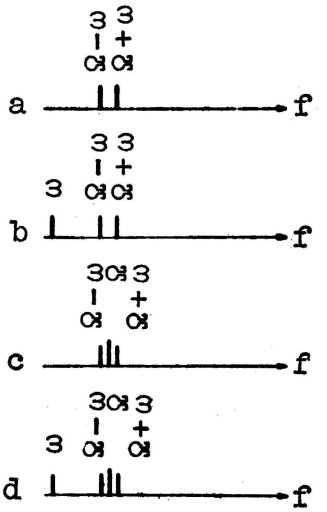

Fig. 4
Frequency spectra of the quadripole modulator.

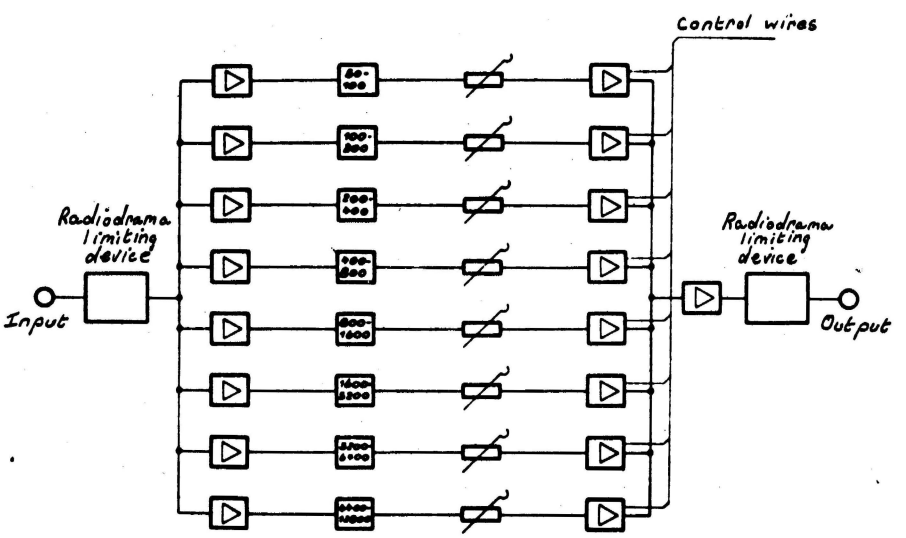

Fig. 5
The filter circuit with remote control.

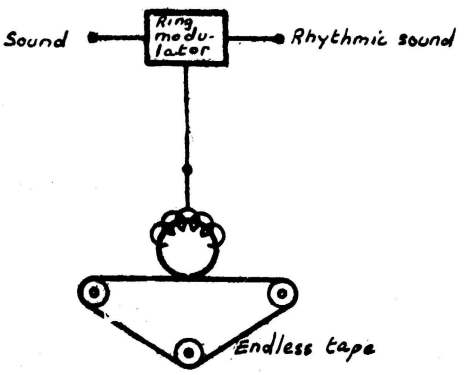

Fig. 6

Imposition of rhythmic structure on sounds by means of a ring modulator and tape loop.

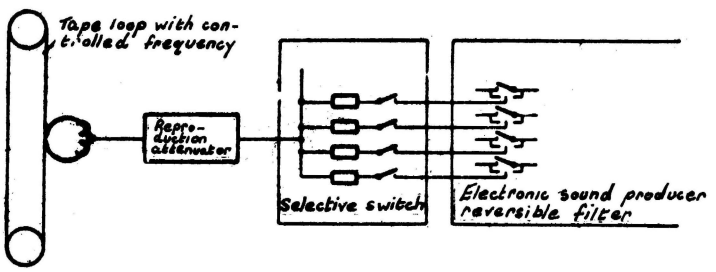

Fig. 7

Control of electronic sound and noise sources by means of audio frequencies over tape loop and selective switches.

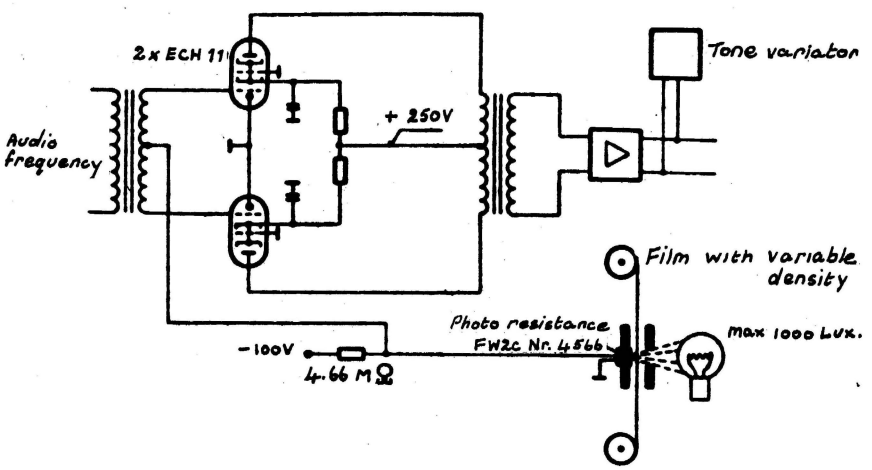

Fig. 8

Circuit diagram of the apparatus for obtaining rapidly changing dynamic structures.

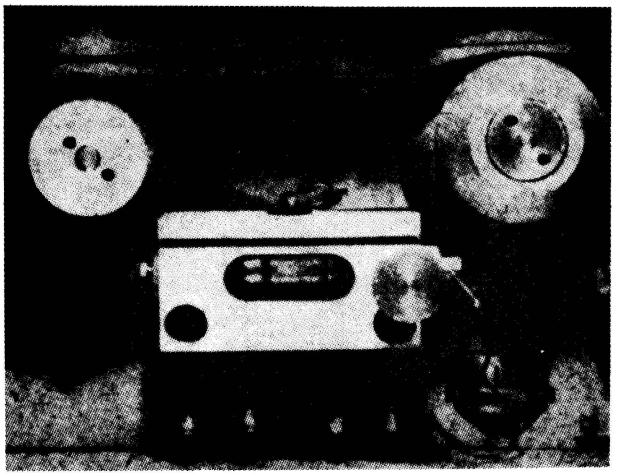

Fig. 9

Photoelectric scanner of the apparatus for obtaining rapidly changing dynamic structures.

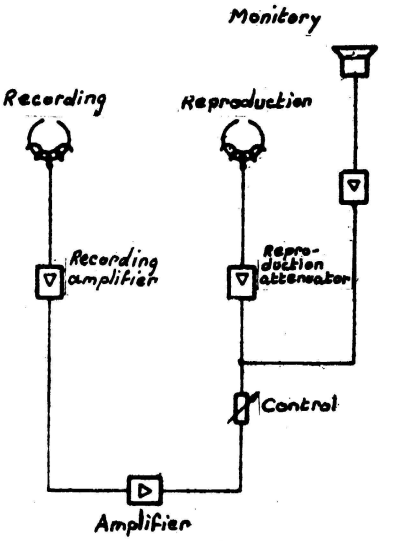

Fig. 10

Feedback Magnetofon.

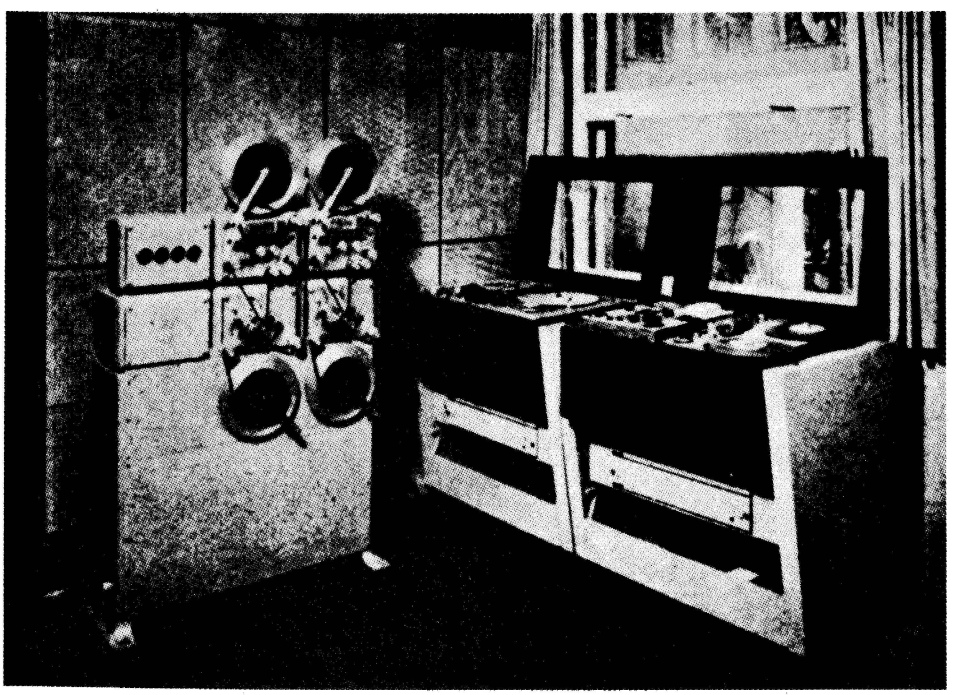

Fig. 11

Magnetofon mechanism for recording and reproducing channels.

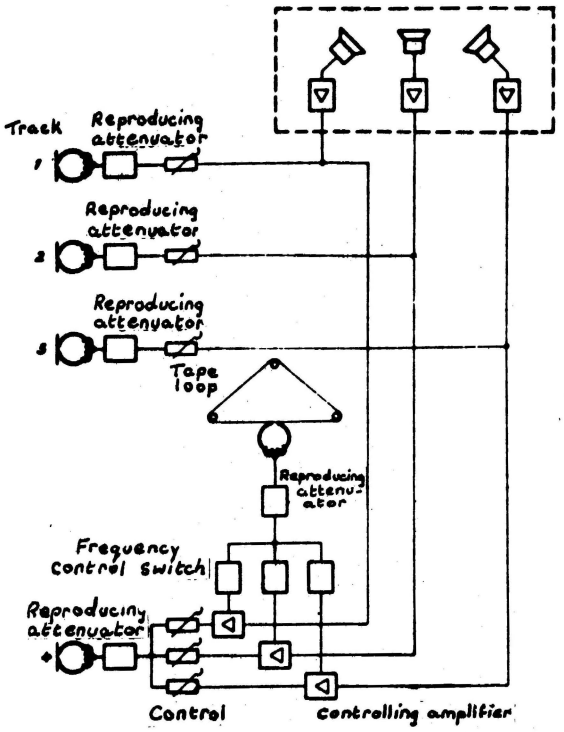

Fig. 12

Arrangements for spatial representation of sound structures.

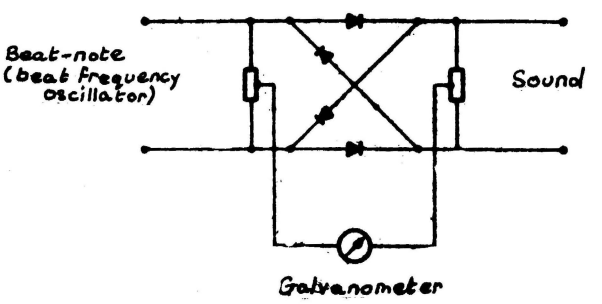

Fig. 13

Beat-note analysis with ring modulator and reflecting galvanometer.

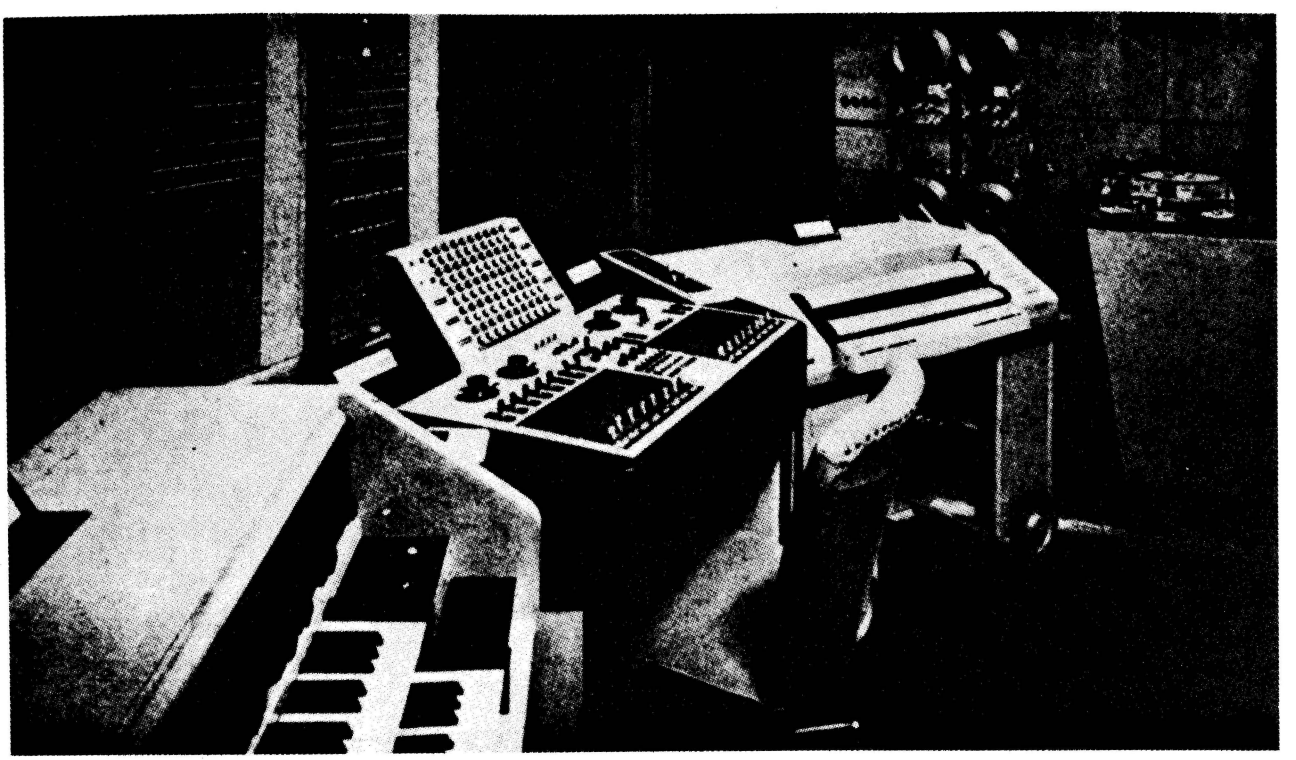

Fig. 14

View of the Electronic Music Studio.

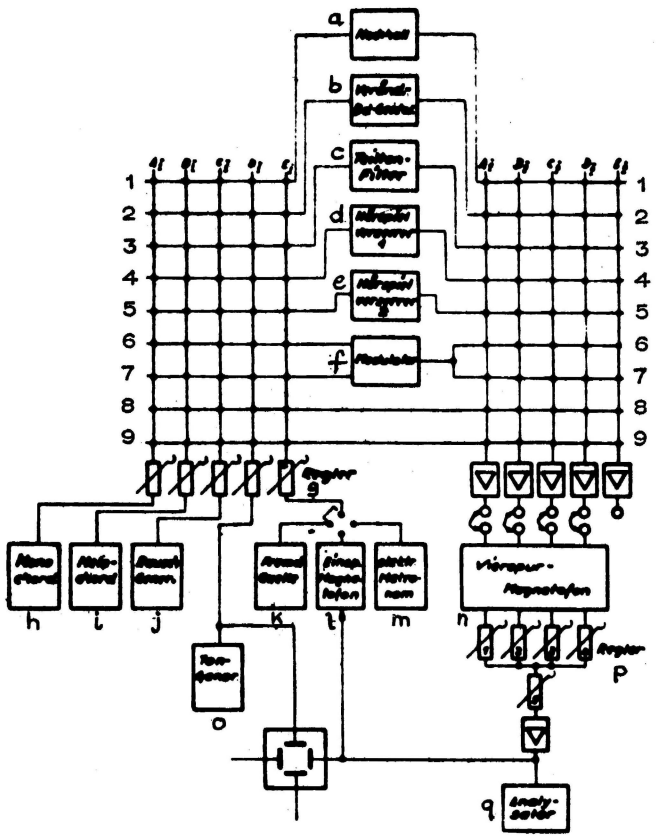

Fig. 15

Modulation block diagram of the Electronic Music Studio.

a. Nachhall = Resonance
b. Veränd-Bd-Geschw. = Variable tape speed
c. Teilton-Filter = Partial note filter
d & e. Hörspiel verzerrer = Radiodrama limiting device
f. Modulator = Modulator
g & p. Regler = Controls
h. Monochord = Monochord
i. Melochord = Melochord
j. Rausch Gener. = Noise generator
k. Fremd Quelle = Alien tone source
l. Einsp. Magnetofon = Single track Magnetofon
m. Elektr. metronom = Electric metronome
n. Vierspur-Magnetofon = Four-track Magnetofon
o. Ton-Gener. = Note generator
q. Analysator = Analyser