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THE ELECTRONIC MONOCHORD

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THE ELECTRONIC MONOCHORD

Summary

The electronic monochord, which was designed entirely to meet the requirements of electronic music, was based on the principles of the Trautonium. It is a two-tone instrument and has a new kind of playing device permitting continuous variation of the frequency. A formant filter provides numerous variations of the spectral characteristics of the sounds produced.

In 1952 the electronic music studio of the Cologne Radio Station, which was designed by F. Enckel largely on the basis of suggestions made by W. Meyer-Eppler, commissioned the present author to develop and design an electronic sound producer which was to be based on experience with the Trautonium but was to differ from it by putting more emphasis on the question of "original composition technique"[1,2]. In order to express this idea clearly in the name as well, the term "Trautwein Electronic Monochord" was chosen for the Cologne instrument.

While in purpose, design, and actual use, especially in the hands of O. Sala, the Trautonium is an instrument which permits a highly artistic rendering of music, enabling the player to give a new artistic performance each time the same piece of music is played over again, original music is a workshop operation which may require considerable time. Hence, the element of spontaneity is absent. Therefore, the design of a sound producer for original composition need not have any special playing aids to facilitate rapid changes of tone colour and register without interfering noises.

Nor were the subharmonic mixed stops, which are characteristic of the Trautonium, incorporated for the time being, since the principle applied for original composition, namely that of superimposing recordings of several voices played separately on a single sound track, permits the production of such effects, although correspondingly more time is required. At the same time it should be realized that a device equipped with all the aids needed for a highly artistic rendering of music is also well suited for use in an electronic studio and would certainly not be a disadvantage. However, owing to limitations of time and price, the project was confined to the minimum expenditure needed for the task.

The electronic monochord in Cologne (Fig. 1) corresponds approximately to the previous version, the concert Trautonium, which had been obtained in 1936 by the Reichsrundfunkgesellschaft (German Broadcasting Company) from Telefunken and which was installed in the Berlin Radio Station, where it was used in numerous broadcasts up to 1945[3]. However, in the new version subharmonic tones and the means of changing the register with the aid of lateral pedal motions were omitted for the reasons explained above.

Externally the concert Trautonium more or less resembles the new version, the mixed-stop Trautonium. Each of these types contains two monophonic electronic sound producers in the one cabinet. In the mixed-stop Trautonium, and to a limited extent also in the concert Trautonium, coupled notes of the subharmonic series may be added to the single note so that when a given note is played harmonics resonate with it; in other words, a mutation stop is provided.

Fig. 2 shows the block diagram of the monochord. It is very important that the frequency of the sweep generator be continuously variable. The division of the frequency range into fixed semitone intervals (keyboard) is necessary for polyphonic

musical instruments, because free pitch selection, which is characteristic, for example, of stringed instruments, is beyond human capacity for more than two, or possibly three, simultaneous voices. However, if it is not the purpose of the individual player to produce polyphony but rather to play music expressively, the player must have a freely variable frequency range at his disposal. Stringed instruments only partially satisfy this requirement. The frequency range of a string is limited and the frequency itself is inversely proportional to the length of string in each case. However, human perception of pitch corresponds to an exponential law, similarly to the Weber-Fechner law of aural sensitivity.

For a tempered note starting from a = 400 c.p.s. the following applies:

$$\nu = 400 \cdot 2^{h/12} \text{ c.p.s.,} \qquad (1)$$

where ν is the frequency, h the number of semitone intervals of a given note from the tuning pitch.

It is desirable that equal distances on the playing device should correspond to equal musical intervals, h. However, the quantity h must be variable not only by fixed semitone intervals but also continuously. Hence, the playing device must be so designed that the following fundamental relation holds for the frequency ν and the distances x on the playing device:

$$\nu = e^{x} \cdot a_{o}, \qquad (2)$$

where a_o is the dimensional constant. A sweep generator (e.g. of the thyratron type) in which the frequency ν_1 is variable with the grid voltage, where the ignition potential can be taken as proportional to the grid voltage x, satisfies the relation(4).

$$\nu_1 = \frac{a_o a_1}{\ln(1 + x)} + b_1. \qquad (3)$$

By suitable selection of the constants a_1 and b_1, i.e., the slope of the voltage on the playing device and a fixed grid potentional, it may be possible to obtain almost complete agreement between relations (2) and (3) over a wide range, i.e., that an increase in the frequency ν according to equations (1) and (2) corresponds to a linear change in voltage on the playing device.

In its simplest form the playing device of the Trautonium thus consists of a resistance wire (or a resistance string), which is stretched across a metal rail. With linear taper approximately equal intervals are thus obtained over about three octaves. The two outer octaves will be slightly narrower than the centre one, but this should have little effect on the performance.

In the electronic monochord of the Cologne studio the resistor at which the grid voltage decays, is coiled around a drum of elliptic cross-section. The return connection is provided by a piece of brocaded material enveloping the resistance drum at a distance of a few millimetres. The winding pitch in this design can be so arranged that the interval spaces along the entire playing device are exactly equal. Elastic keys have been placed above the playing device so that the desired frequencies may be easily selected. It is well to have five keys over each octave so that the pattern of the black keys of a keyboard is obtained (Fig. 3). The keys may also be tuned to other pitches in the way shown in Fig. 1.

The sweep generator with ignition voltage frequency stabilization feeds a saw-tooth voltage with an exponential curve of amplitude, inversely proportional to the pitch (the time constant remains unchanged over a range of 3 or 4 octaves), to the anode of the thyratron or of a similarly acting tube circuit. Both of these elements are in good agreement with the acoustic properties of conventional musical instruments. The low notes - great amplitude, strongly exponential character - are

slightly richer in overtones than the high ones with their almost linear curves. Inasmuch as amplitude uniformity of all pitches and a higher overtone content is desirable for authentic composition, the voltage may be taken from a cathode resistance into which only the very brief discharge surges flow. The amplitudes of the latter can be made independent of the pitch in a follow-on amplitude filter. The upper limit depends on the requirements from case to case.

Formant filters serve for the formation of tone colours (Fig. 2). These filters consist of band filters, acceptor circuits and suppression filters which permit selection of a widely variable frequency effect. The filters are controlled by the keys which can be seen at both sides of the playing device in Fig. 1. The formant filters are followed by the level controls W44, an amplifier V41 and the tone variator.

In the mixed-stop Trautonium subharmonics may be drawn from the saw-tooth oscillations of the generator in synchronized generators. In television, for example, a subharmonic of a given order must be derived from a fixed frequency. It would be obvious to a television engineer that the problem is different here in that the circuit must permit selection of subharmonics of different order at will and that once selected, a subharmonic ratio must be maintained over a range of 3½ octaves. This problem has been solved adequately up to the 24th subharmonic. The subharmonic saw-tooth oscillations may be filtered either in company with the controlling oscillation through the same filter, or through separate filters. The expenditure for a mutation stop is thus almost as great as that for a melody stop. However, the resulting acoustic effect should justify the use of the subharmonic mixed-stop principle for original composition technique as well as other musical purposes, e.g. concert performance, in the future development of the instrument.

An essential difference between electronic sound production and sound transmission is the much greater dynamics of the former. An electroacoustic transmission channel remains the same for weak and strong signals so that the signal-to-noise ratio becomes unfavourable for small signals. However, in electronic sound production as shown in Fig. 2 this ratio remains constant. The player controls the dynamics only at the end of the system. The noise level is reduced practically to zero, or, more accurately, to the point where only the environmental noise remains.

For the concert hall a loudspeaker output of 150 w. is required in order to attain an effect comparable to that of a large orchestra. The signal energy thus obtainable is approximately 110 db. Although original composition technique is restricted to the signal energy of the magnetic tape, it should nevertheless be pointed out that during microphone transmission of very loud sounds (e.g. O. Sala's interpretation of the Satan scene in Honegger's "Joan of Arc at the Stake") a volume equal to the acoustic volume is transmitted over the radio loudspeaker, even if the signal energy is clipped, presumably because of stereoacoustic effects. In original composition a similar process might also be utilized in order to achieve an impression of great volume with low signal energy.

On each manual two devices have been provided for controlling the signal energy: a pedal (level controls W44) and a control consisting of a pressure-dependent resistance which is placed underneath the elastically supported playing device. There is no model for this control in related fields. By means of a variable pressure up to approximately 200 $gm. cm.^{-2}$ and a stroke of a few millimetres control over a range of approximately 50 db. can be attained without frictional losses. Capacitive and inductive methods were found to be unsuitable, but a liquid resistance has been used successfully for many years. Because

so few models have been produced to date, development of a powdered carbon type, or the like, has not yet been considered worthwhile.

It is important that the control (fade-in control) should govern the build-up and fall-off processes as well as the signal energy. The science of acoustics, of course, considers these processes very important in explaining tone colour[5,7]. Experience with the Trautonium shows that only the envelope curve of the transient phenomenon, not the phase position, determines perception of tone colours. This is supported by the fact that it makes no difference for the perception of tone colours whether the fade-in control is inserted ahead of the terminal amplifier or between the sweep generator and the filter. In the latter case the fundamental oscillation can begin only in the cosine phase, whereas in the former it can begin in any phase whatsoever. The shape of the envelope curve is very important. In the Trautonium it is formed by the player by finger touch. It should be possible to produce specific envelope curves for every type of tone colour with the aid of mechanical devices, but it must be remembered that the envelope curves differ somewhat at different positions on one and the same instrument. In his investigations on electric scanning of string oscillations W. Nernst arrived at similar results[6].

The assumption of H. Backhaus[7], that some frequencies other than those of the steady state occur in the transient phenomena, was not confirmed by experience with the Trautonium, since there are no differences in frequency here between transient phenomena and the steady state. On the other hand, it is a very interesting fact that the tone colours of nearly all known musical instruments and vocal tones may be well simulated by the method of forming sounds, vocal and instrumental ones, by periodic impulse excitation of systems capable of natural oscillations. This method was first suggested by the present author in 1930. However, the literature, particularly with

respect to the Voco-Vocoder development in the U.S.A., gives the credit to K.W. Wagner(8). Even professional instrumentalists often find it difficult to detect the differences. For sounds of stopped organ pipes and clarinets an antisymmetric periodicity of the impulse excitation is required(3).

The above statements are not intended as an expression of opinion on the aesthetic problem of sound simulation. However, an objective account of the development and experimental results would appear to be a valuable contribution just now to radio broadcasting because it has for the first time adopted a form of active musical composition in the "Studio for Electronic Music" in Cologne.

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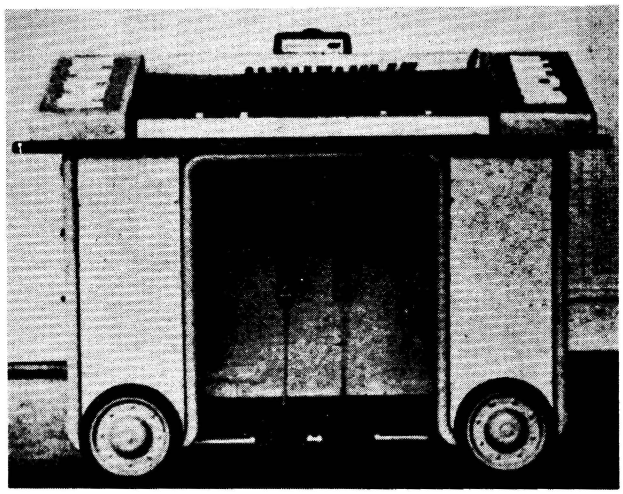

Fig. 1
The electronic monochord.

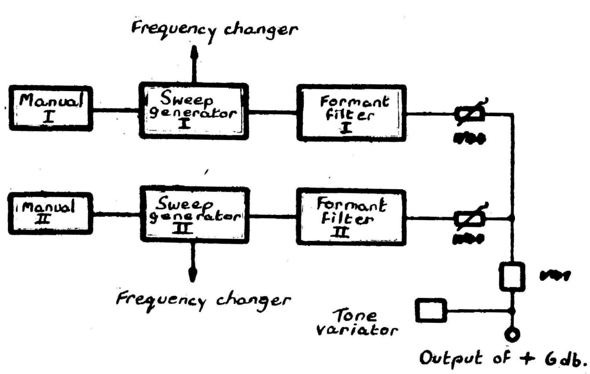

Fig. 2
Block diagram of the electronic monochord.

Fig. 3
Playing device of the electronic monochord.