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ELECTRONIC MUSICAL COMPOSITION NO. 2, 1953

BY

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ELECTRONIC MUSICAL COMPOSITION NO. 2, 1953

Summary

By means of a composition written in simple harmonic tones (sinusoidal oscillations) it is shown how electrical sound sources are able to produce the material for sequential constructions in the three variables, "frequency", "sound intensity" and "duration".

During the last few months I have written the first composition for sinusoidal tones and produced it in the Electronic Music Studio of the Northwest German Radio Broadcasting Station at Cologne.

After a period of preparatory listening and testing I decided not to use any electronic sound sources which produce ready-composed sound spectra (melochord Trautonium), but only to employ sinusoidal tones from a frequency generator ("pure" tones without overtones). Sinusoidal tones differ from each other only in frequency and amplitude. Thus, when I used simple frequency and amplitude conditions for the musical construction the sound will have to be a result of these combinations.

1. Hypothesis

A "series system" for sensorially evaluated frequency intervals shall begin in the centre of the auditory range and move out towards the limits of audibility in both directions.

The duration of each tone shall be inversely proportional to the value by which its frequency differs from the central frequency, i.e., as the tones move farther and farther away from the central frequency their durations will become smaller and smaller.

The sound intensity series shall decrease with increasing frequency distance from the centre, proportionally with respect to the duration. Thus the directions outwards from the centre towards the lower and upper limits of audibility will be reflected in correspondingly decreasing duration and intensity of the tones.

The derivation of tone sequences ceases when the limits of audibility are reached. This boundary is encountered at the point where differences of pitch are still just distinguishable, i.e., where the frequency-time and frequency-volume curves indicate limiting values.

The movement towards the boundaries is not to be taken as a development, i.e., a constant, progressive evolution, but as a contact which is possible at any moment during the passage of time. In this way a series structure can be chosen for all three dimensions. Its extreme values - depending on its situation with respect to time - reach the above circumscribed limits in permutating order.

2. The Composition Pattern

A1. Frequencies

The ratios between the following series are intervals of the overtone series: descending minor tenth; ascending major third; descending minor sixth; ascending minor tenth; descending major third:

$$\frac{12}{5} \qquad \frac{4}{5} \qquad \frac{8}{5} \qquad \frac{5}{12} \qquad \frac{5}{4}$$

Taking a given initial frequency and multiplying by each of these factors in turn we obtain a series of six tones. The above factors were chosen so that the resulting series would just reach the lower boundary region of pitch audibility when the

initial tone was selected in the centre of the audible range. The lowest frequency in the next series is 66 c.p.s. (further extension to the boundary of audibility by transposition, see under D). To begin with, therefore, we have the tone series, and by multiplication each calculated frequency constitutes the starting point of a new series (Table I).

I break off here because any further continuation of the process would go below the boundary of 66 c.p.s.

A2. Groups

The introduction of a series consisting of tone mixtures ("groups") in my last two works made clear to me the contradiction between the use of predetermined spectra (instruments) and a consequent introduction of timbre into the structure of the series.

By composing with sinusoidal tones this contradiction is resolved. The timbre is now determined firstly by the number of sinusoidal tones combined into a group, secondly by the frequency ratio between these tones and thirdly by the intensity of each partial.

"Composition" begins with the "grouping" of the tones. From the frequencies columnized in Table I, I take groups of not more than six elements in the following order:

4 5 3 6 2 1

This series was chosen because in the first place no symmetry or monotonic order was to be permitted, and in the second place the possibility of the same frequency or a frequency ratio of 1:2 (octave) occurring in one group was to be avoided. The application of the above grouping plan to Table I therefore

yields the following frequency combination (in c.p.s.):

4	1920	5	800	6	1000	2	625
	800		333		417		260
	1000		417		521	1	325
	625	3	260		325		
	1500		625		781		
	1200		500		625		etc.

This plan of compounding tone mixtures from pure tones is employed for the formal construction of the entire work: tones form tone mixtures ("tone groups" - vertically); tone mixtures form sequences ("sound groups"- horizontally); sequences form structures ("sequence groups" - horizontal or vertical), i.e., from a single row of groups we obtain a uniform proportion of the entire work. Thus, for example:

4 { Tones in tone mixture 1
Sounds in sequence 1
Sequences in structure 1 }

5 { Tones in tone mixture 2
Sounds in sequence 2
Sequences in structure 2 }

3 { Tones in tone mixture 3
Sounds in sequence 3
Sequences in structure 3 }

etc.

The structures are, as stated, vertical (simultaneous) or horizontal (successive) groupings of 1 to 6 sequences. For this I selected six structure-group forms.

The following are groups:

1. Sequences horizontally (subordinate pause time* before tone time).

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*See under C "superordinate and subordinate times".

2. Sequences horizontally (pause time after tone time).
3. Sequences vertically (pause time before tone time) (begin simultaneously).
4. Sequences vertically (pause time after tone time) (begin simultaneously).
5. Sequences vertically (pause time before tone time) (end simultaneously).
6. Sequences vertically (pause time after tone time) (end simultaneously).

For characterizing the groups of the structures I chose the following asymmetrical sequences determined by the formal over-all conception:

4 2 3 5 6 1

B. Sound Intensities

The idea underlying this work is that the series orders of the three "dimensions" (frequency, sound intensity and time) proceed outwards from the central auditory range to the boundary regions. For the sound intensity this means that the tones tend to become inaudibly soft as the frequencies touch the inaudibly low and high ranges and the times approach the limits of tone recognizability.

For this purpose, the time was first linked to the frequency interval (distance from the centre) so that it was inversely proportional to the functional relationship (the lower, the shorter).

Between the sound intensity and the frequency there is a relationship which is normally expressed by the Fletcher Munson curves. If each tone of a series descending from a

central frequency region has the same intensity the sensation of volume will decrease with the depth.

The same applies to a series of tones ascending with equal sound intensity for all tones. Thus a pure tone of 80 c.p.s. with 70 db. (50 phons) corresponds to a tone of 1000 c.p.s. with 50 db. (50 phons) as far as the volume experienced is concerned, and both these, in turn, correspond to a tone of 16,000 c.p.s. with 70 db. (50 phons). This frequency-dependence of the volume, produced precisely what I was seeking, namely that the series of disturbing tones from the central auditory region to the boundary regions would be heard more softly.

Thus, by determining the six different volumes, both for the 66 c.p.s. tone and for the 1920 c.p.s. tone by means of the same scale of sound intensities one to six (in db.), the required auditory result is obtained, namely that low and high tones become progressively softer as they are farther and farther away from the central region.

The proportional series of frequencies started from tones which themselves were related to the tone of origin (1920 c.p.s.) in accordance with the series:

1920 c.p.s.	800 c.p.s.	1000 c.p.s.	625 c.p.s.	1500 c.p.s	1200 c.p.s.
800 "					
1000 "			etc.		
625 "					
1500 "					
1200 "					

These initial tones of the proportional series shall be of equal value. Therefore they have equal sound intensity. I have characterized the six-fold increasing distance from the initial tones through the proportional series by a constant sound intensity difference value (4 db.), so that the frequencies

in combination with the sound intensities appear as follows:
(n db. = maximum sound intensity, still to be determined)

1920 c.p.s.	n -	db.	800 c.p.s.	n	db.	1000 c.p.s.	n	db.
800 "	n—4	"	333 "	n—4	"	417 "	n—4	"
1000 "	n— 8	"	417 "	n— 8	"	etc.		
625 "	n—12	"	etc.					
1500 "	n—16	"	(compare Table I).					
1200 "	n—20	"						

The strongest component of the next group of tones follows from the above sound-intensity relationships to the frequency series. Thus the sound-intensity relations in first six tone groups are:

k_1 Group 4

1920 c.p.s.	n	db.
800 "	n— 4	"
1000 "	n— 8	"
625 "	n—12	"

k_2 Group 5

800 c.p.s.	n	db.
333 "	n—4	"
417 "	n— 8	"
1500 "	n—16	"
1200 "	n—20	"

k_3 Group 3

260 c.p.s.	n	db.
625 "	n— 4	"
500 "	n— 8	"

k_4 Group 6

1000 c.p.s.	n	db.
417 "	n— 4	"
521 "	n— 8	"
325 "	n—12	"
781 "	n— 16	"
625 "	n— 20	"

k_5 Group 2

625 c.p.s.	n	db.
260 "	n— 4	"

k_6 Group 1

325 c.p.s. n db.

k_2 Group 5

1500	c.p.s.	n—16 db.
1200	"	n—20 "
800	"	n "
333	"	n—4 "
417	"	n—8 "

During the piece the entire sequence of frequencies (see Table I) is used six times. Each time it is used the determination of the strongest component in the series of six is changed, so that each frequency in turn produces the strongest partial tone.

Example (first group of six in the six passages):

1.

1920	c.p.s.	n db.
800	"	n—4 "
1000	"	n—8 "
625	"	n—12 "
1500	"	n—16 "
1200	"	n—20 "

2. after 216 frequencies

1920	c.p.s.	n—20 db.
800	"	n "
1000	"	n—4 "
625	"	n—8 "
1500	"	n—12 "
1200	"	n—16 "

3. after 432 frequencies

1920	c.p.s.	n—16 db.
800	"	n—20 "
1000	"	n "
625	"	n—4 "
1500	"	n—8 "
1200	"	n—12 "

4. after 648 frequencies

1920	c.p.s.	n—12 db.
800	"	n—16 "
1000	"	n—20 "
625	"	n "
1500	"	n—4 "
1200	"	n—8 "

etc.

The maximum sound intensity of each group has an order of its own. The intensity order is:

— 20 db.
— 24 "
— 28 "
— 32 "
— 36 "
— 40 "

The determination of the gain of the partial is thus relative, since it is made to depend strongly on a superordinate group sound intensity. But not only must the intensity of the components in the tone mixture be relative, but also the maximum sound intensitites of the tone mixtures in the sequences.

Thus each group of tone groups - i.e., each sequence - again receives a maximum intensity. These sequence intensities follow the same order as the tone mixture intensities, based on the formal principle of the groups and the times (see A2 and C).

In order to realize this second relativity of intensities each sequence has been placed opposite itself in another intensity as a "sequence echo".

First a sequence is heard with the maximum intensity of the loudest tone mixture. Then in the "sequence echo" the maximum intensity for the sequences is determined according to the intensity series of tone mixtures (the sequence echoes have been especially characterized by a slight dying away, the reverberation in each case being 20 db. weaker than the strongest tone mixture of the sequence echo).

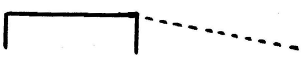
This gets around the following difficulty: Let us take the extreme case where a tone mixture of gain stage 6 (— 20 db.), which contains a 6th partial with the sound intensities n — 20 db. (hence — 40 db.), depends on a sequence gain stage 6. Thus a scale up to — 60 db. will be required. When placing sequence and sequence echo opposite each other, on the

other hand, I remain within the gain range of 0 to — 40 db.

The gain series for tone mixtures and sequence echoes is also used to determine maximum intensities of the structures. This is explained more fully in section D (maximum intensity of structure transpositions).

In order once more to distinguish the tone groups clearly from each other, the following six envelope forms are selected:

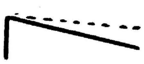
1.  (without change of sound intensity)

2.  (without change of sound intensity, reverberation added)

3.  (increasing from the audibility threshold to the required maximum intensity)

4.  (increasing, reverberation added)

5.  (decreasing from maximum intensity to audibility threshold)

6.  (decreasing, reverberation added)

The series of envelope curves is asymmetrical:

4 2 3 5 6 1

This envelope series also determines the sequence echoes (following the general principle of form).

C. Tone Time

It has already been stated that the tone times are to be inversely proportional to their pitches.

In order to obtain simple relationships the times were determined as follows: The number of centimetres representing the length of time occupied by a tone on a tape at the rate of 76.2 cm./sec. shall be equal to 1/10th of the frequency of the tone. The original choice of frequencies has already been determined by this time relationship.

The times are therefore (see frequency plan):

192 cm.(76.2 cm./sec.)	80.0 cm.(76.2 cm./sec.)	
80 "	33.3 "	
100 "	41.7 "	
625 "	26.0 "	etc.
150 "	62.5 "	
120 "	50.0 "	

The smallest time reached is 6.6 (66 c.p.s.) (approximately 1/11th sec.).

Let each time so determined be called the superordinate time. For, within this superordinate time there is also a subordinate time proportion between tone and silence, which varies between 1/6 and 6/6. In other words, tone and silence together make up the superordinate time. Each tone occurs during

$$\frac{1}{6} \quad \frac{2}{6} \quad \frac{3}{6} \quad \frac{4}{6} \quad \frac{5}{6} \quad \frac{6}{6}$$

of the superordinate time, and what is left is the pause. Whether the ratio is pause to tone or tone to pause depends on the structural form (see A2).

For the internal time proportions I chose the series:

$$\frac{2}{6} \quad \frac{4}{6} \quad \frac{6}{6} \quad \frac{3}{6} \quad \frac{5}{6} \quad \frac{1}{6}$$

The choice was made with reference to the minimum occurring time values of the low frequencies, for which a maximum proportion (5/6 or 6/6) was sought (5/6 tone + 1/6 pause or 6/6 tone, no pause).

However, the tones are grouped in series (see A2, sounds). In each tone, group one tone is the strongest (see B relative sound intensity). This strongest tone in a vertical group determines the time of its group ("duration of sound"). In the six different columns of the frequency series the first, second, third, fourth, fifth, sixth tones of the series of six, as already stated, are successively raised to the greatest intensity, so that in the course of the piece each frequency serves at least once to determine a sound time, i.e., it is the strongest tone in a vertical group.

Thus the times of the tone mixtures are a logical consequence of the interplay between relative sound intensities and group determination. The proportion of subordinate to superordinate time thus depends only on the strongest tone of a given group.

As already stated, I have transferred the relativity of time to the "sequence echoes". For this I used the same series,

$$\frac{2 \quad 4 \quad 6 \quad 3 \quad 5 \quad 1}{6}$$

i.e., the sequence echoes do not repeat their sequences with the same times, but only part of them, namely

$$\frac{2}{6} \quad \frac{4}{6} \quad \frac{6}{6} \quad \frac{3}{6} \quad \frac{5}{6} \quad \frac{1}{6}$$

of the sequence time (measured from the end of the sequence "echo").

Since the time of a tone mixture is proportional to the frequency of the strongest tone, then the time of a sequence is the sum of the tone mixtures and the time of a structure in horizontal sequence grouping is equal to the sum of the sequence times and their "echoes", while in vertical sequence grouping it is equal to the longest sequence together with sequence echo. Thus, the duration of the piece is the sum of the structures.

D. Formal Equalization

Everything stated thus far has half fulfilled the conception of the piece. That is to say, the limiting values have been approached in one direction only, towards zero. This is because of the one-sided frequency generation downwards, followed, of course, by times and intensities proportionally.

The same should also occur upwards, towards "infinity". For this purpose a reflection of all proportions is made: each structure is placed opposite itself in a transposition. The transposition intervals follow the original frequency proportions:

$$\frac{12}{5} \quad \frac{4}{5} \quad \frac{8}{5} \quad \frac{5}{8} \quad \frac{5}{4} \quad \frac{5}{8}$$

(+ 5 permutations of this series over its own proportional values).

Thus structure 1 stands opposite its transposition one minor tenth below it. Structure 2 is a major third above its transposition, etc.

This transposition of structures was achieved by changing the tape speed, i.e., the higher the transposition, the shorter and softer the tones, and vice versa. Between the original structures and their transpositions, an equilibrium has been found that satisfies the structural concept of the piece.

In both high and low registers the short and long times are balanced against one another while frequencies, as well as sound intensities, move towards the limits of audibility.

The maximum sound intensities of the structural transpositions are varied according to the same series as those of the sounds and sequence echoes.

I attempted to bring this composition to a state of equilibrium. I therefore started from the function of state of a series system and I attempted to bring its conception into agreement with the natural functions of the three dimensions frequency, time and intensity.

3. Notation

Fig. 1 shows the first side of the staff. The four systems are to be read simultaneously for the first structure:

Structure I - 4 sequences; vertical; begin simultaneously; pauses follow.

The first sequence (upper system) has four sounds (the first sound four sinusoidal tones, etc.) The "sequence echo" (E): $\frac{2}{6}$ of the sequence time, maximum gain stage 3 (= − 8 db.).

The second sequence (second system from the top) has five sounds. Then the sequence echo: $\frac{4}{6}$ of the sequence time; maximum gain stage 4 (= −12 db.).

The third sequence (second system from the bottom) has three sounds. Sequence echo: $\frac{1}{6}$ of the sequence time; maximum gain stage 2 (= −4 db.).

The fourth sequence (bottom system) has 6 sounds. Sequence echo: $\frac{3}{6}$ of sequence time; maximum gain stage 1 (= 0 db.).

With the changing key in all four stages the structural transposition begins simultaneously in the ratio of 12:5, maximum gain stage 3(= – 8 db.).

Each system has two parts: a logarithmic line system for drawing the frequencies with ten lines and below the heavier centre line a system of lines equally spaced for the sound intensities or envelope curves of the tones or tone mixtures. In front of each system is the frequency figure 100 to 1000, i.e., each field between the lines in logarithmic distance constitutes a 100 c.p.s. field.

If frequencies beyond the range of 100 to 1000 c.p.s. used here are to be noted, I use keys.

For simplicity and clarity only octave keys are employed:

2 means that all frequencies about an octave are raised (frequency multiplied by 2)

4 signifies two octaves higher (frequency multiplied by 4)

$\frac{1}{2}$ signifies one octave lower (frequency multiplied by $\frac{1}{2}$).

In practice any arbitrary transposition key is possible ($\frac{3}{4}$, $\frac{4}{4}$: fourth or third transposition), in order to transpose the frequencies into such a decade.

If tones are then very widely separated they will be distributed over several systems of various keys.

The horizontal dashes between or on system lines 1 to 10 thus represent the time and frequency of the partials. The frequency figure is written in units on each line. This number should be added to the bottom hundred stroke of the system, i.e., the number 12.5 between the 3rd and 4th hundred-line of the system means 312.5 c.p.s., and hence with octave key "2" it means 625 c.p.s. (see first tone mixture in the upper system).

Continuation of a frequency line in dashes signifies reverberation. The strongest component of a vertical group has been drawn more heavily. The gain values in the additional partials then follow the letters b, c, d, e, f (in each case a difference of 4 db.).

The lower system division (in this case 8 lines) stands for the sound intensity. It is therefore capable of noting eight different sound intensities of the tone mixtures of 4 db. difference in each case. This is the scale "0" from 0 to −28 db. By changing the sound intensity key 0 and writing in its place −4 or −8 the entire sound intensity scale is displaced and can be expanded arbitrarily (with −4 for example, by −4 db; with −8, by −8 db., etc.).

The envelope curves with the maximum sound intensity to be read in each case are represented in the obvious way. The time is given in cm. below the envelope curves. In this case the length of tape is drawn in a scale of 1 : 20 (76.2 cm. of tape length, therefore occupies 3.8 cm. in the drawing = 1 sec.). Small arrows at the end of the frequency strokes and in the corresponding envelope curves indicate that these tones or sounds continue as reverberations until a vertical stroke terminates the faded sequence echo.

Time indications without corresponding frequency and sound intensity notations are pauses.

Table I

Frequencies in c.p.s.

12 :	5	8 :	5	5 :	4
	4 :	5	5 :	12	
1920	800	1000	625	1500	1200
800	333	417	260	625	500
1000	417	521	325	781	625
625	260	325	203	488	390
1500	625	781	488	1170	937
1200	500	625	390	937	750
800	333	417	260	625	500
333	138	173	108	260	208
417	173	217	135	325	260
260	108	135	84	203	162
625	260	325	203	488	390
500	208	260	162	390	312
1000	417	521	325	781	625
417	173	217	135	325	260
521	217	271	169	407	325
325	135	169	106	254	203
781	325	407	254	610	488
625	260	325	203	488	390
625	266	325	203	488	390
260	111	135	84	203	162
325	138	169	105	254	203
203	87	105	66	158	127
488	108	254	158	381	305
390	166	203	127	305	244
1500	625	781	488	1170	937
625	260	325	203	488	390
781	325	407	254	610	488
488	203	254	158	381	305
1170	488	610	381	914	732
937	390	488	305	732	586
1200	500	625	390	937	750
500	208	260	162	390	312
625	260	325	203	488	390
390	162	203	127	305	244
937	390	488	305	732	586
750	312	390	244	586	469

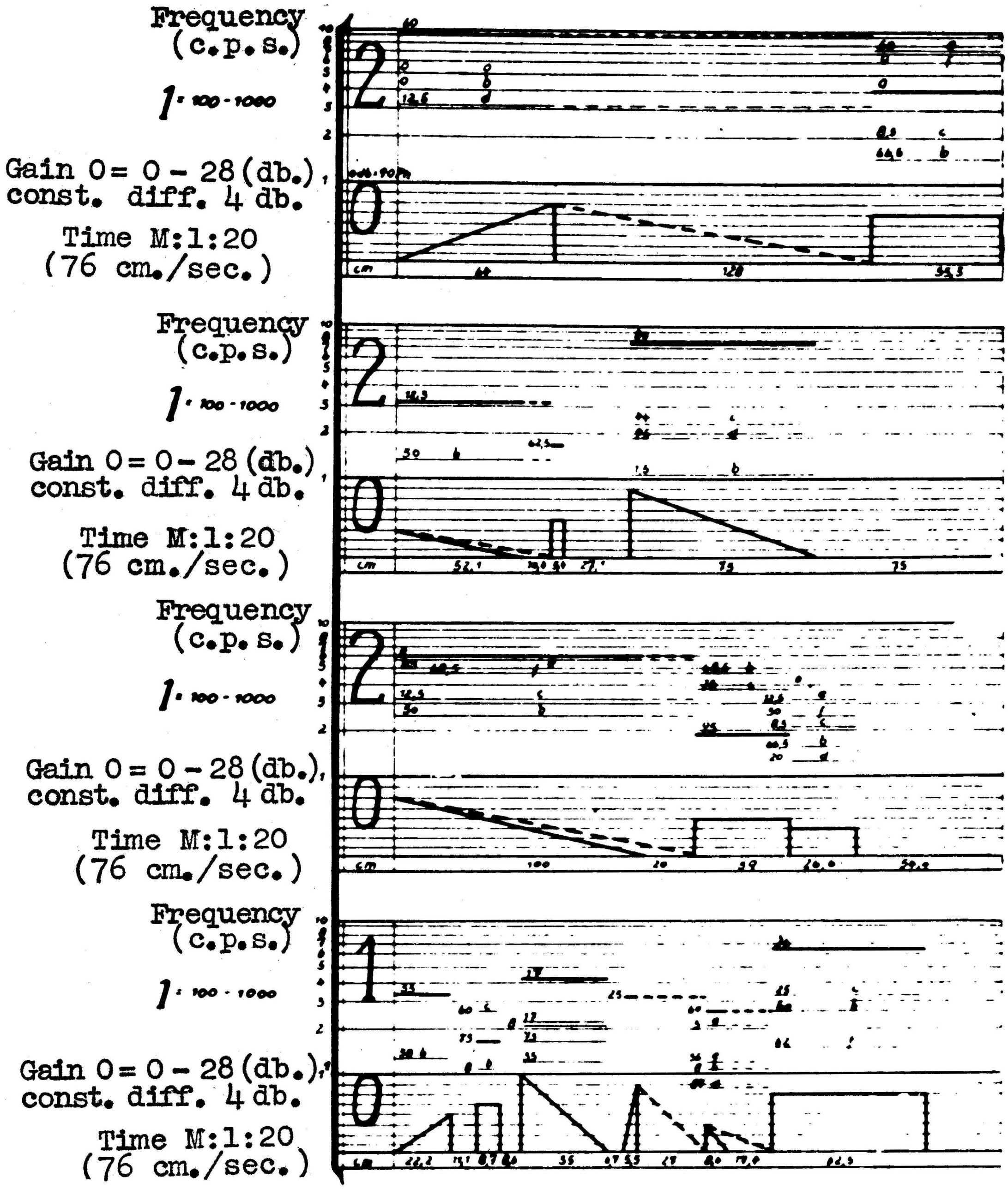


Fig. 1
Example of notation