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Sonograph and Sound Mechanics

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I AM very grateful to the sponsors of this Conference for giving me the opportunity of presenting in America some results of my research in Switzerland. Personal contact cannot be replaced by any other form of communication. Translating scientific material from one language into another is an especially difficult task, and personal explanations avoid many misunderstandings. I also thank Professor Locke for his help in phrasing the present paper in English.

1. PRELIMINARY DEFINITIONS

I constructed the word *sonograph* from the Latin "sonus," "sound," and from the Greek "graphé," which means an "action" of engraving or of writing. It designates a new class of electracoustical instruments. Such an instrument comprises essentially an *electronic* part (impulse generator) converting sounds into simplified groups of electric impulses, and a *mechanical* part, which transforms these impulses into characteristic actions like graphic symbols or remote control. When this mechanical part includes a drawing oscillograph or a typing machine, we talk about a *steno-* or a *typo*-sonograph respectively. The electrical part may select predominantly speech-characteristics of sounds; then we speak about a *phonetic* sonograph (or phonetograph). This kind of instrument may translate speech sounds into a natural stenography or into the conventional alphabetical letters. The sonograph has a physiological character because similar transformations of acoustical oscillations into (electro-chemical) impulse groups seem to happen in ear, nerves, brain, and muscles. Further, the electrical part of the sonograph may select other characteristics of sounds than phonetic ones: for instance, heart sound, music, emotion, or animal cries.

The complete nomenclature of possible sonographs cannot be given here, as the descendants of a potential grandfather are hardly known at the time when he is just a child learning to write.

2. DUALISTIC NATURE OF SOUND IN AIR AND NERVES

Before describing the sonograph, it may be useful to recall some different known physical and physiological aspects of sound and of corresponding symbols.

(a) What is the aspect of sound in air and resonators?

In Fig. 1, lines 1 to 7 show oscillograms of the spoken syllable "ke," as they appear on the screen of an oscilloscope. Lines 11 to 17 show 7 partial oscillograms of the same syllable "ke," when it is decomposed by 7 octave band filters. They allow a rough representation of what is probably happening in the 24,000 fibers of the basilar membrane of the ear. We see that the essential sine wave components are between 150 and 4800 cycles per second. (Anticipating the later description of the sonograph, the dotted lines show which part of these partial oscillations the sonographic principle would operate on.)

(b) What further physiological aspects of sounds may be noticed?

Without restricting the question to hearing, Figs. 2 and 3 show general shapes of individual signals in some nerve fibers. According to Fig. 2, one nerve fiber is able to transmit energy only during a short time, like 1 millisecond; afterwards it is tired. It must relax for another short time, like some milliseconds. Hence, there cannot be any trace of frequencies over 400 impulses per second, nor of continuous energy-transmission. Nerve fibers have their own rhythms. They transmit energy in an intermittent manner. As the acoustical nerve includes many thousands of individual fibers whose working is not synchronous, the resulting transmitted signals have various shapes. According to the investigations of Davis and Galambos, the frequencies of signals are various functions of the controlling acoustical *frequencies* between 100 and 3000 c.p.s. (cycles per second).

Figure 3 shows another category of nerve-signals used, for instance, for heart-regulation, as a function of the blood pressure. We see that the impulse frequency varies between 10 and 50 per second when the pressure varies between 40 and 200 mm of mercury. Here we find a direct relation between *intensity* of stimulus and frequency of nerve signals.

Another physiological relation is shown by Fig. 4: the result of five discontinuous asynchronous signals in different fiber groups is a nearly continuous muscle contraction. The frequencies of the individual signal may vary between 5 and 50 per second resulting in little or great contraction *intensity*.

(c) What is the corresponding rhythm between sounds and visual symbols?

We now take the example of speech sounds. Language means communication of thoughts. Each thought may be decomposed into ideas or images. Each image corresponds to one word and to one individual visual picture. Each spoken or written word may be decomposed on the average into four elementary sounds, called phonetic elements (or phonemes) and into four corresponding symbols or alphabetical letters.

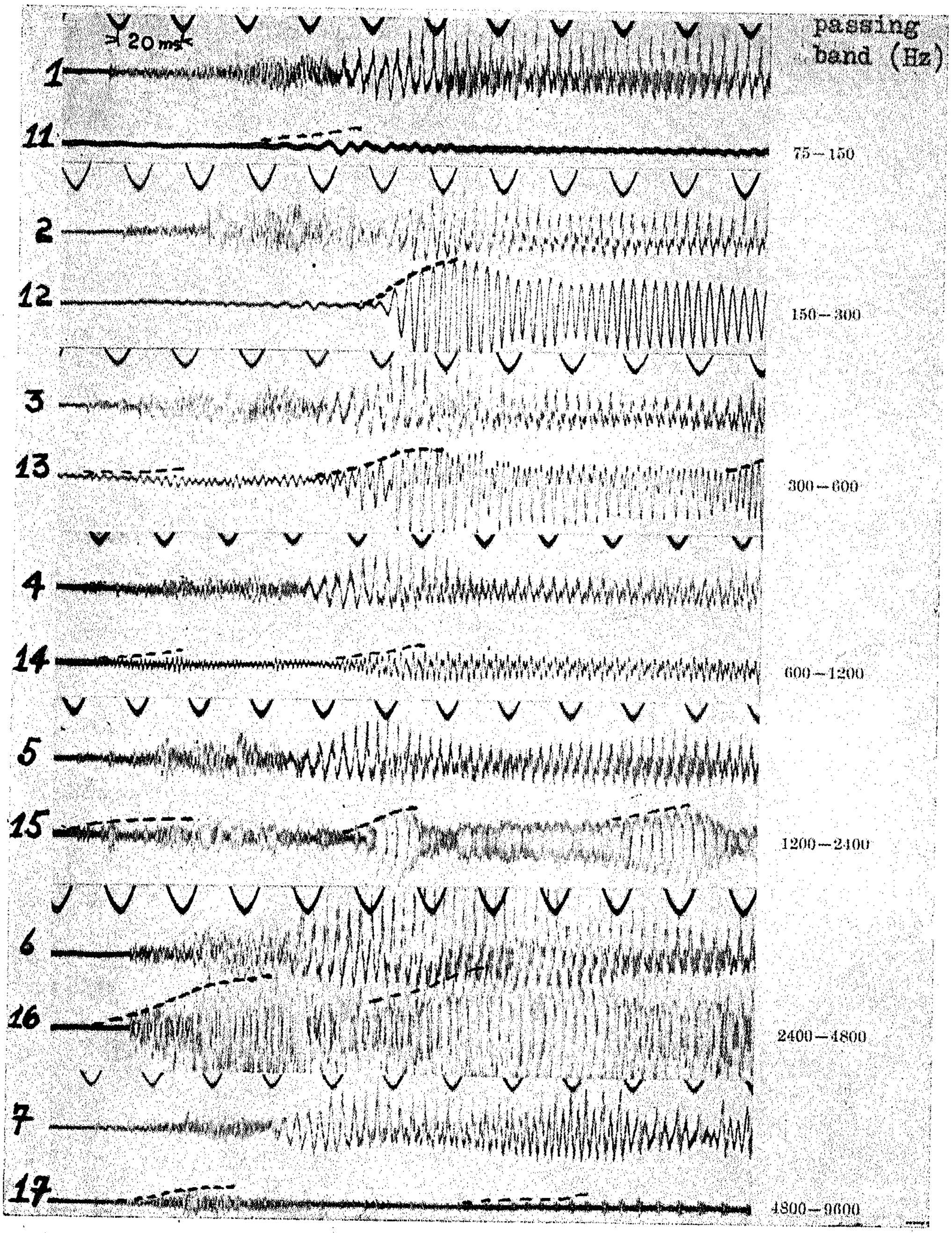

FIG. 1. Oscillograms of seven octave bands of the spoken syllable "ke." The dotted lines (added by the author) show which part of these oscillograms the sonographic principle operates on. (From F. Trendelenburg, 1935.)

Western European languages allow for articulating on the average of 12 phonetic elements per second; that means communicating orally 3 words or pictures per second from one brain to another. This is nearly the speed of thinking itself, because individual perception of pictures begins to become confused when their speed exceeds 3 per second.

What we have summed up here in a few words is the result of the more or less unconscious work of mankind extending over tens of thousands of years from pre-history to about the year 1500 B.C., the age of the alphabetical writing.

Figure 5 shows the first known Phoenician alphabet, derived from Egyptian hieroglyphics, which is the father of all known alphabets.

(d) What is the conclusion of the preceding outline?

The oscillatory aspect of sound in the air and in the basilar membrane is only part of what makes up a

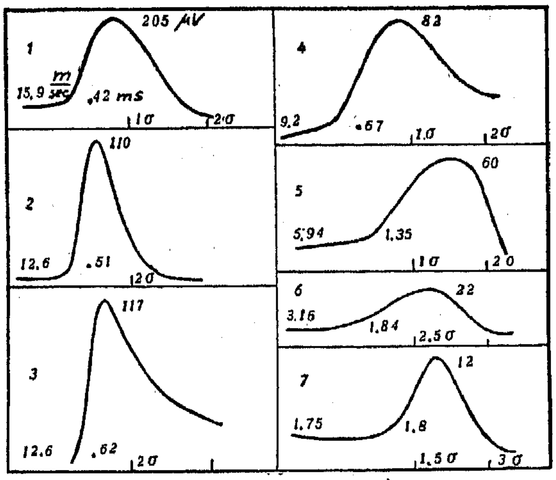

FIG. 2. Seven different types of impulses in individual fibers of a frog nerve. (From A. v. Muralt, 1946, after Erlanger, Gasser, Schaefer.)

sound. Continuous (stationary) phenomena are unknown in nerves; they act in an intermittent manner. Generally speaking, sounds are associated to many classes of frequencies and rhythms. Their average values may be tabulated in a simplified manner as follows:

in the air	2000 cycles/sec.
in one nerve fiber	200 impulses/sec.
in one muscle fiber	30 impulses/sec.
in the brain	12 elements or symbols/sec.
corresponding images	3 words or pictures/sec.

The rhythm of 12 elementary sounds (phonemes) per second allows the spoken language to follow nearly the speed of thinking. We may talk nearly as fast and effortlessly as we think. But our hand is not able to do the same and to draw or to type perhaps 12 complete symbols or alphabetical signs per second. Isn't it possible to build a machine which could translate spoken sounds into written symbols? A machine which could write directly what we say? This question is at the origin of

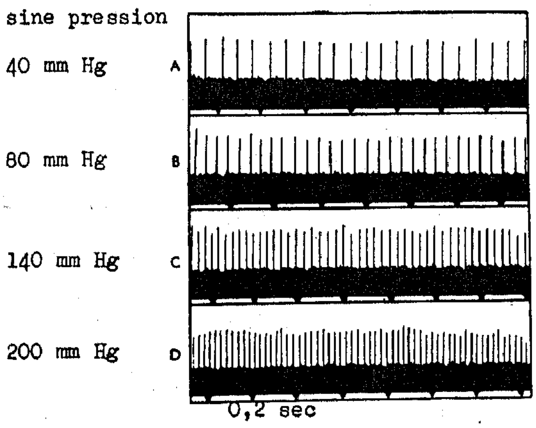

FIG. 3. Individual action currents in a sensitive carotissinus nerve fiber. (From A. v. Muralt, 1946, after Bronk and Stella.)

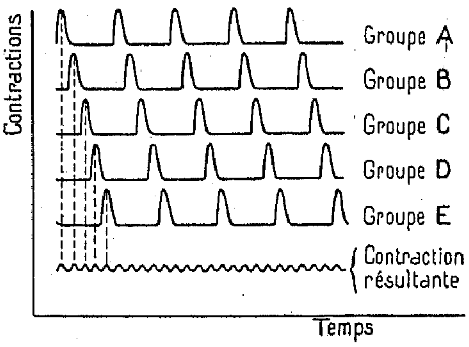

FIG. 4. Illustration of continuous muscle contraction resulting from five discontinuous contractions in fiber groups. (From Soula, 1947.)

the sonograph. And we shall now leave consideration of sound itself to enter into the techniques of the sonograph.

3. TECHNICAL PRINCIPLES OF THE PHONETIC STENO-SONOGRAPH

According to the scheme of Fig. 6, each sound, like the phonetic element "e", i.e., appears first physically as an acoustical wave group, carrying an oscillation V_1 of atmospheric pressure during a time variable between 30 milliseconds and some seconds. This sound "e" originates in the mouth of a speaker. What is this mouth? An orchestra of resonators which are excited by voice or breath, and which amplify at will some frequency bands called "formants." The vocal cords vibrate with fundamental frequencies situated somewhere between 90 and 400 cycles per second.

According to my investigations for French phonetics, the resonators of the mouth orchestra are essentially six in number and their formants are situated round the frequencies 200, 500, 1000, 1500, 2000, and 3000 cycles per second. The midpoints of these formants are very far from each other, the first three being separated by octaves and the last three by fifths. This simplicity of mouth orchestra explains why the same person may definitely sing wrong and speak right. Our acoustical wave group appears thus as a concert of six principal sine waves, some of them are reinforced at will by the speaker. Optically we could compare the mouth with a six-color pallet, the tongue with a brush, and the phonetic element with a picture where some colors are dominant.

Now we look at the principal organs of the sonograph: it includes a microphone and an amplifier converting the oscillation in air V_1 into an electrical one V_2. This is decomposed into 6 partial oscillations V_{31} to V_{36} by 6 resonators or filters corresponding to the 6 principal formants of the mouth orchestra.

Then, each partial oscillation is rectified and the acoustical frequencies are eliminated; only the energy envelopes V_{41} to V_{46} subsist.

Each envelope generally includes an initial increasing part (corresponding to the arrival of the wave group), a

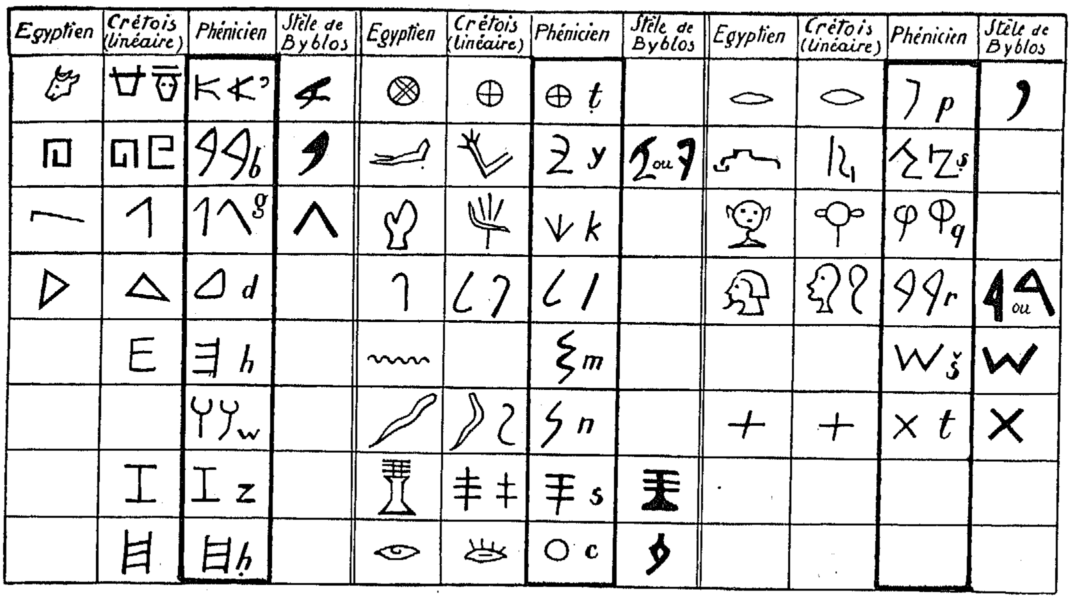

FIG. 5. The first known "Phoenician Alphabet" of 22 consonants (about 1500 B.C.), compared with some older Cretan and Egyptian signs. (From J. G. Février, 1948.)

quasi-stationary middle part, and a final decreasing part. In principle, the sonograph uses only increasing parts. It converts them by positive time derivative into a concert of initial impulses V_{511} to V_{516}. These are then transformed into mechanical actions by the vectorial ink-oscillograph which draws a symbol like C_{1-6} resulting from the 6 impulse components C_1 to C_6.

Each symbol pictures instantaneously the positive energy variations of the frequency spectrum in polar coordinates. By varying the relative intensities and phases of the components, the key of the symbols may be changed.

The paper surface covered by the moving oscillograph stylus may be compared to a circular pallet divided into 6 sectors, each of them being associated to a color from dark to light, that is, from low to high sounds (from 100 to 4000 cycles). Figure 7 reproduces sonograms of pure tones from 100 to 3500 cycles per second; they are recorded by the vectorial oscillograph type *ODD* 61 of the sonograph type *SSP* 62.

4. SONOGRAPHIC SELF-MODULATION

The instrument so-far described was the result of research extending over many years, and it was realized four years ago. But in spite of its apparently correct principle, it did not work satisfactorily; it was not able to decompose a word into its alphabetical elements. For every word it furnished a diagram similar in principle to the old pre-alphabetic Chinese or Egyptian pictographic signs. To get an alphabetical script, it would have been necessary to spell each word before the microphone.

So it was necessary to pursue further research.

Now the solution of the problem has been found. The complete sonograph also uses the decreasing parts of the energy envelopes V_{41} to V_{46}. It converts them into final impulses V_{521} to V_{526} whose result brings the amplifier back to zero at the end of each sound element.

These final impulses may also be self-excited by a continuous sound, at frequencies variable at will between zero and 20 per second. This allows us to separate the elements of diphthongs.

5. OSCILLOGRAMS OF SELF-MODULATED CONTINUOUS SOUNDS

Figure 8 reproduces 6 oscillograms of acoustical oscillations V_2 of Fig. 6, between 80 and 200 cycles per second, when they are self-modulated 9 times per

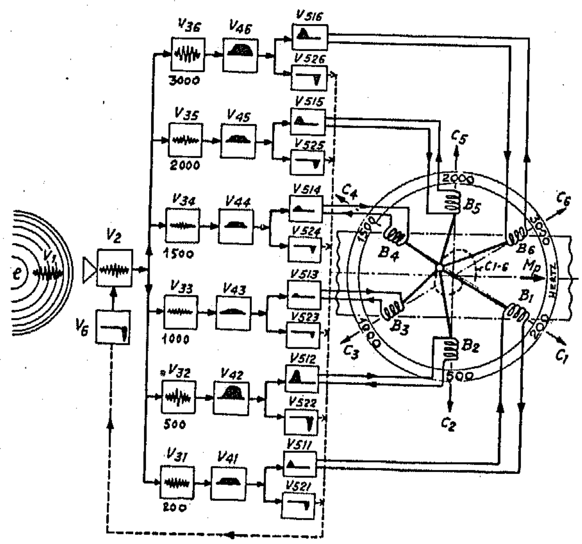

FIG. 6. Schematic diagram of the phonetic steno-sonograph, type *SSP* 61.

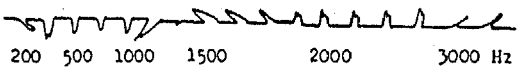

FIG. 7. Sonograms of pure tone from 200 to 3500 c.p.s., recorded by vectorial oscillograph.

second. They are directly recorded from the end-anode of the sonograph amplifier by the ink oscillograph type *OED* 12. Figure 9 shows schematically the self-modulation envelope.

Figure 10 shows the oscillograms of a corresponding sonographic impulse component, like V_{516} in Fig. 6, which is thus self-repeated 9 times per second. It is directly recorded from one coil, like B_1, of the vectorial oscillograph by the ink oscillograph type *OED* 11.

Figure 11 reproduces corresponding self-repeated symbols C_{1-6} of the sound "i," (i), directly recorded by the vectorial oscillograph. When a continuous sound is self-modulated by special shapes of infrasonic "final" impulses, everything happens as if the "arrival" of the sound repeated periodically. And the graphic image repeats for as long a time as the sound lasts.

This also illustrates its duration. Under these conditions, the sonographic resonators or filters periodically go back to zero, either at the rhythm of phonetic elements or faster or slower, at will. Now, sonograph has "understood" the alphabet; it is able to decompose any word into its phonetic "atoms" and to write any sound element as if the preceeding had never existed.

A later study may analyze mathematically the sonographic curves of Figs. 7 to 10 and compare them with the physiological curves of Figs. 1 to 5, or the like.

For the present, we remark only that the sonograph converts a continuous phenomenon into a discontinuous one, similar to the previously mentioned physiological transformations. Figures 12–14 show views of the complete steno-sonograph type *SSP* 62, of the vectorial oscillograph type *ODD* 61, and of the ink oscillograph *OED* 12.

The prototype of the steno-sonograph has been realized in cooperation with workshop master Georges Kung and his students, in the "Ecole d'Horlogerie de Genève," and also with the Ateliers Latour, Genève. Its working has been demonstrated to about thirty invited specialists on December 22, 1949 in the Technicum de Genève. It is also shown by a news-film of the Ciné-Journal Suisse, taken in my laboratory on January 23, 1950, which I shall project here.

We may insert now a little philosophical digression. What is physics? The science of the measurable phenomena. Therefore, a phenomenon does not exist physically without a receiver able to measure it, and its description is incomplete if the transmitter is not known.

Receiver, phenomenon, and transmitter form together a kind of trinity unit. What I called a connection in former publications like "The Ellipsoid Theory of Wave

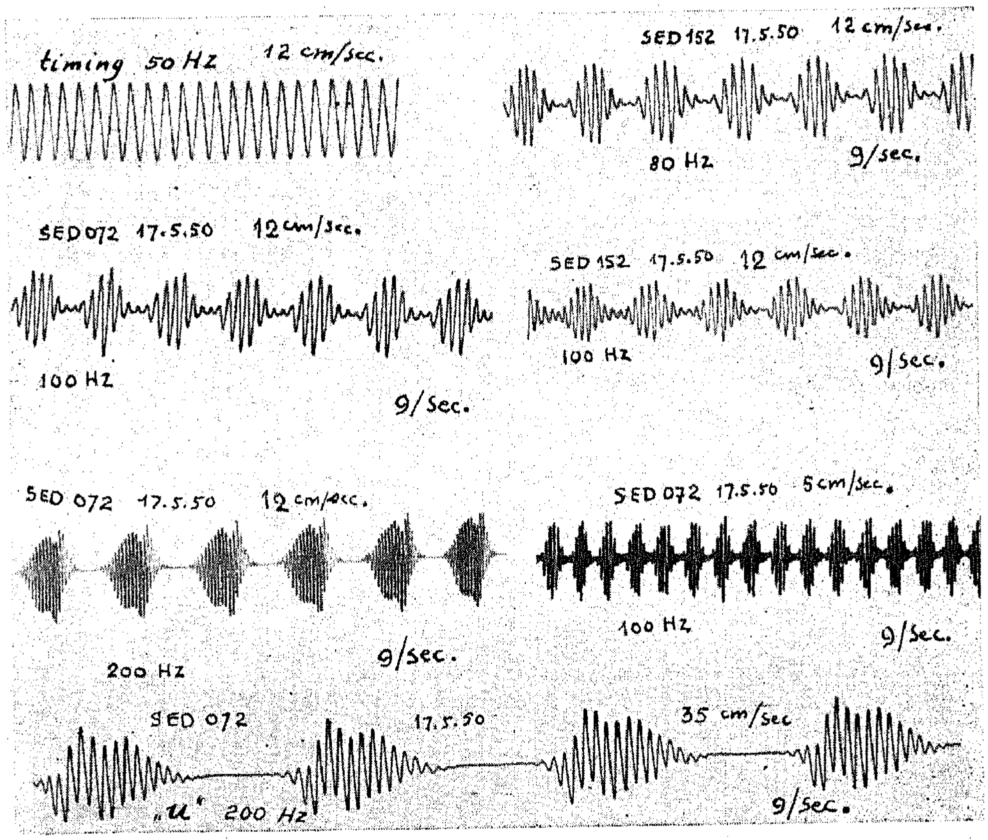

FIG. 8. Different shapes of acoustical oscillations, self-modulated 9 times per second, in sonograph-amplifier (recorded by ink-oscillograph type *OED* 12).

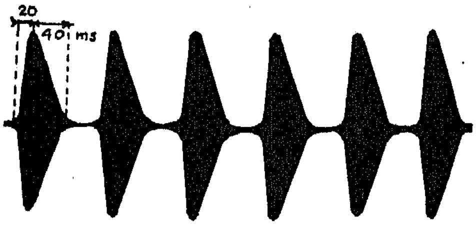

FIG. 9. Acoustical oscillation, self-modulated 9 times per second, in sonograph-amplifier.

Connections," where I attempted to make a new "Physics of Connections," complementary to the classical and relativistic field theories, and giving much simpler results in the case of wave diffraction, for example.

In the case of speech, we have to deal with a "phonetical connection." The natural transmitter is "brain plus mouth," the natural receiver is "ear plus brain," the phenomenon is the "speech sound." Therefore, the sonograph, which is essentially an artificial sound receiver, must have some brain characteristics which are not included, for example, in ordinary amplifiers and oscillographs.

6. STENO-SONOGRAMS OF SPEECH

The relative intensities and phases of the 6 components C_1 to C_6 in Fig. 6 may be varied at will, thus allowing a large number of alphabetical keys.

Figures 15 to 18 reproduce some examples of fairly similar steno-sonographic alphabets and some sonograms of spoken words like "physique," [*fizik*], "souriceau," [*suriso*], "New York," [*njujɔrk*] "Boston," [*bɔstn*].

Because sonograph research had extremely modest material means furnished by the inventor himself, the progress has been very slow and the first actual prototypes have not yet reached technical perfection allowing immediate popular applications.

But it is not far from the aim, and in any case, it has proved that the sonographic principle allows practical translation of sounds into symbols. Further, it opens the way to the *typo*-sonograph which is now in preparation.

7. TECHNICAL PRINCIPLES OF THE PHONETIC TYPO-SONOGRAPH

(a) With Four Components

The impulse generator (electronic part) of Fig. 19 is analogous to the one of Fig. 6, but to simplify the

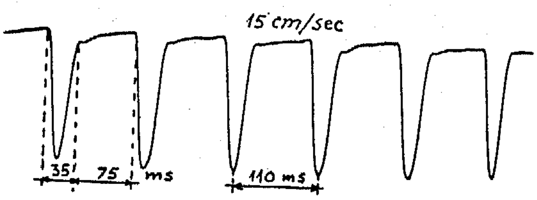

FIG. 10. Single sonographic pulse-component of a continuous sound, repeated 9 times per second (recorded by ink-oscillograph, type *OED* 11).

description, it includes only 4 filters instead of 6; the microphonic oscillation V_2 is thus converted into 4 initial impulses V_{51} to V_{54}.

Further, the vectorial oscillograph of Fig. 6 is now replaced by a *relay combiner* and a *relay integrator.*

As the number of filters is $F=4$, the four impulses V_{51} to V_{54} may be combined two to two in differential relays whose maximum number is

$$D=\binom{F}{2}=\binom{4}{2}=6.$$

The integrator must include a number of action relays equal to the number of keys of the typewriting machine.

Each action relay may be switched by S contact pairs, connected in series and located in different differential relays. If, for example, $S=2$, the maximum number of action relays is

$$A=\binom{D}{S}\cdot 2^s=\binom{6}{2}\cdot 2^2=15\cdot 4=60.$$

And each differential relay includes a maximum number

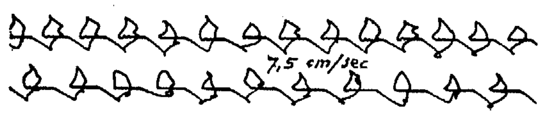

FIG. 11. Sonogram of continuous "*i*" resulting from 6 components (9 and 7 times per second).

of contact pairs

$$P=S\cdot\frac{A}{D}=2\cdot 60/6=20.$$

Each of these (polarized) differential relays may close 10 contact pairs 1_{11} to 1_{10} or 1_{21} to 1_{20}, according to the positive or negative value of impulse difference.

As two contact pairs of a differential relay are each time connected in series, each phonetic element may switch one of the 60 action relays 1_1, 2_1, to 5_1, 6_1, which itself pushes one key of the phonetic typewriter.

Experiment shows that 4 filters are not sufficient in practice. The best number is between 5 and 8, in accordance with the desired degree of differentiation; 6 is the practical number for French phonetics. The relays indicated are of new electrodynamic types.

(b) With F Components

Instead of 4 or 6 (as in Fig. 6 or 19), the number of sonographic resonators or filters may be generalized to F. The tables of Figs. 20 and 21 show theoretical values of the number D of differential relays, of the number S of contacts connected in series, and of the number A of possible action relays, i.e., of possible keys to be operated.

It appears that a number of filters as small as 8

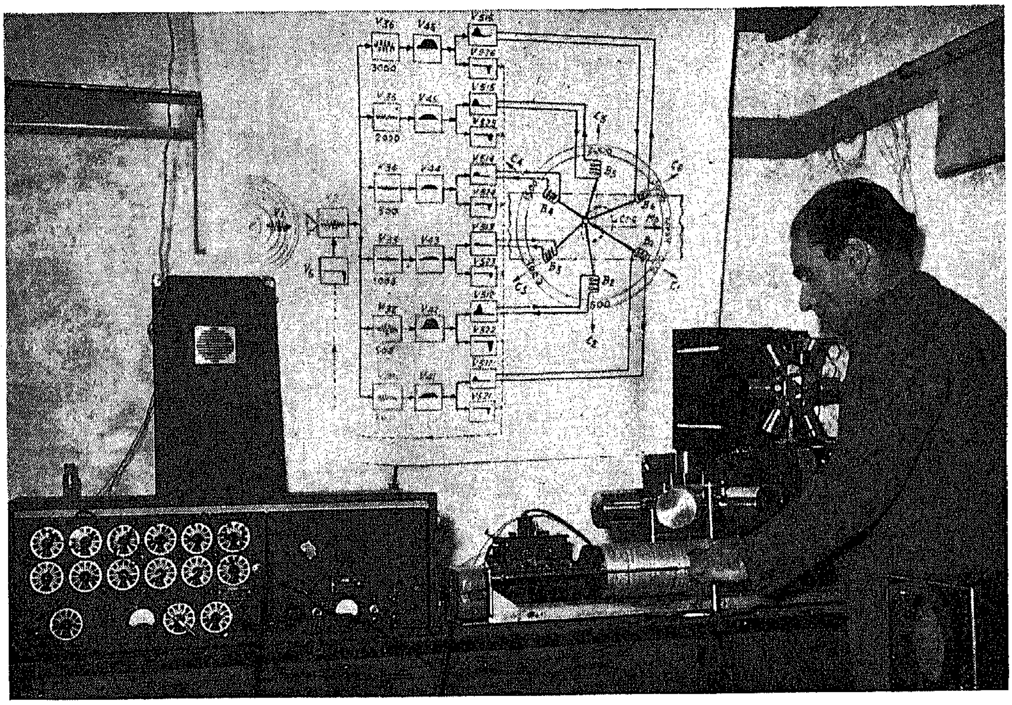

FIG. 12. The phonetic steno-sonograph.

theoretically allows the differentiation of 20 billion sounds. It could be that the basilar membrane does not need to make a physiological Fourier analysis of each sound and that a rougher analysis could allow the brain itself to differentiate an enormous number of sounds.

In the case of language transcription it would only be disturbing to have too fine a differentiation, because the practical number of different phonetic elements is 80 in the maximum and 40 on the average. Therefore, the numbers $F=6$; $D=5$ or 7; $S=3$ or 2; $P=48$ or 18; and $A=80$ may be sufficient for building a complete phonetic typo-sonograph.

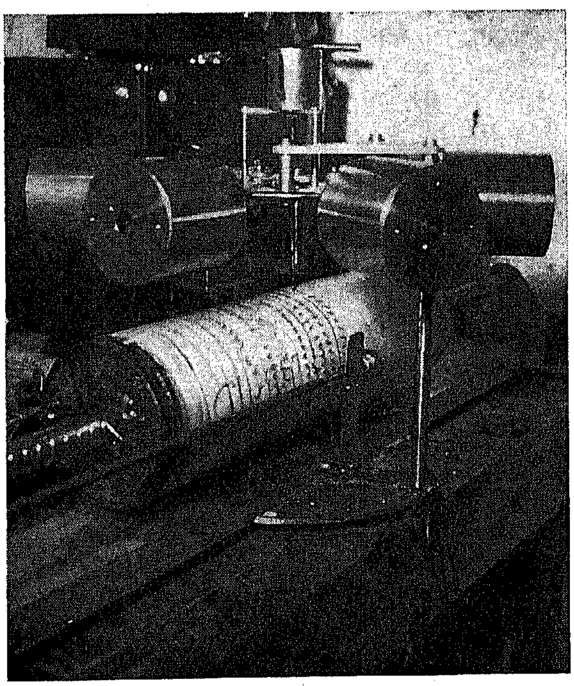

FIG. 13. Two-dimensional oscillograph type *ODD* 61 of steno-sonograph.

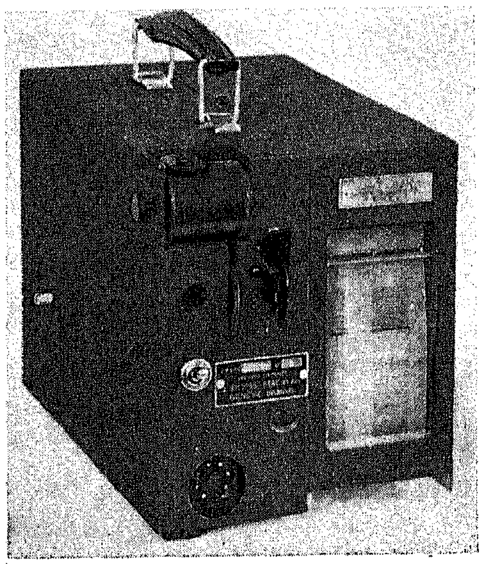

FIG. 14. Ink oscillograph, type *OED* 12.

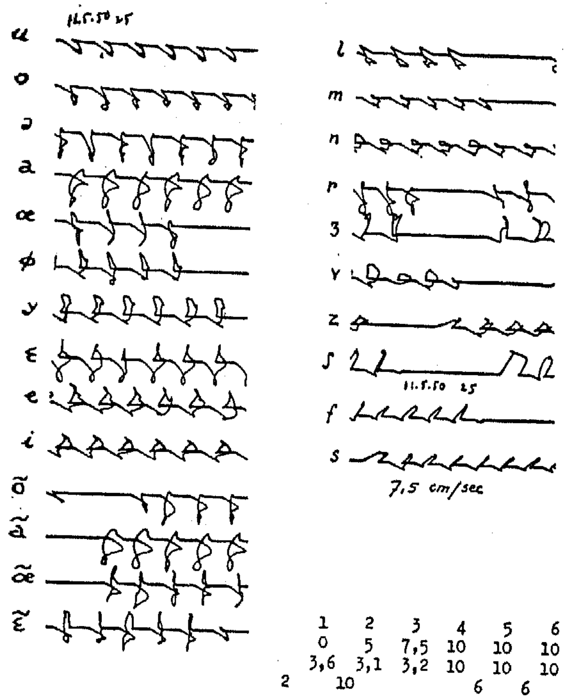

FIG. 15. Sonographic alphabet, type *SSP* 62 No. 5.

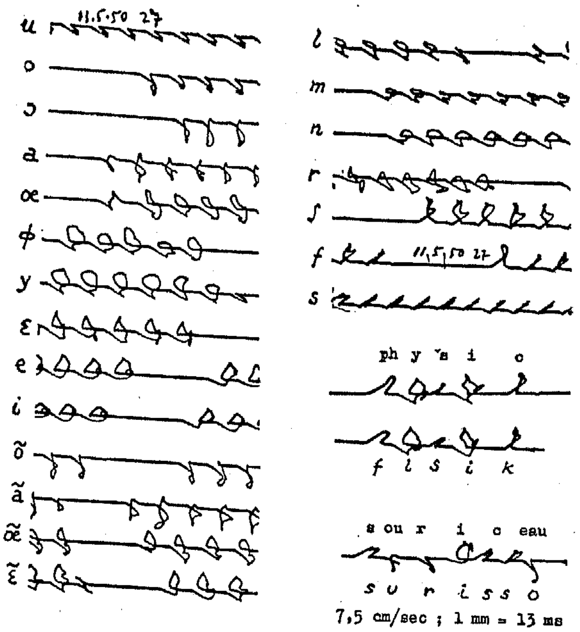

FIG. 17. Sonographic alphabet, type *SSP* 62 No. 6 (continuous sounds, self-modulated 12 times per second) and words.

8. THE FUTURE OF STENO- AND TYPO-SONOGRAPHS

The advantage of typo-sonograph will be that it will write directly intelligible symbols, like the usual alphabetical letters, thus furnishing texts which will be readable without special instructions. Possibly this instrument may contribute to reestablishing a neo-phoneticism, in some new manner reproducing the phonetic purity of the initial Phoenician alphabet.

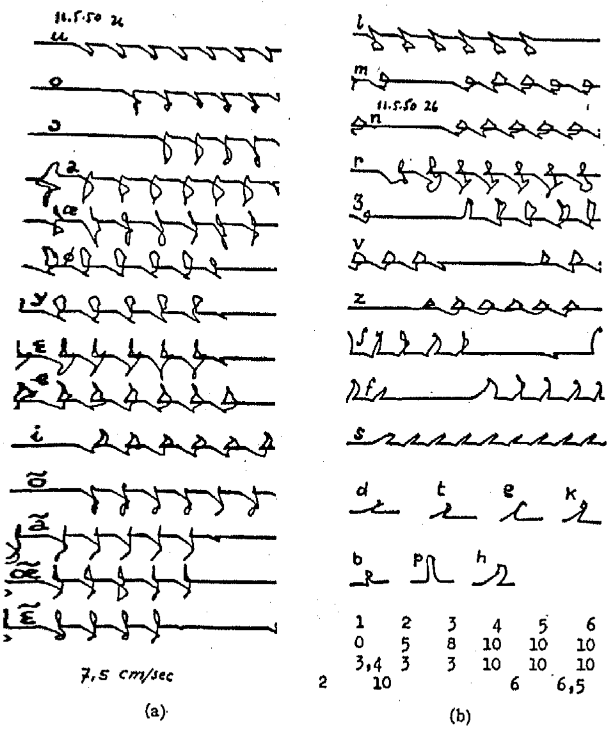

FIG. 16. Sonographic alphabet, type *SSP* 62 No. 3.

But, the steno-sonograph, which may always remain cheaper than the typo-sonograph, will retain its own field of application. It has the advantage of allowing the transcription of any language by means of a small number of natural analytical symbols, which will be easier to decipher than stenographic signs. The applications of sonographs are not limited to translation of spoken words into written ones; they may be used for

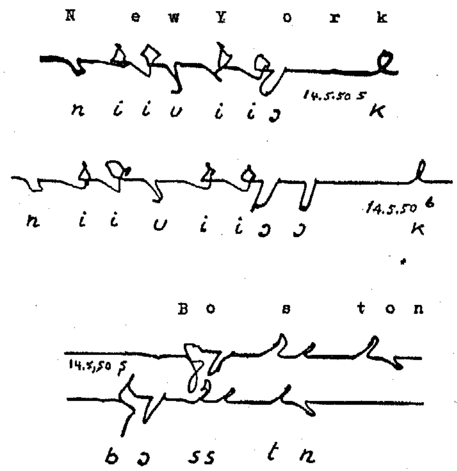

FIG. 18. Steno-sonograms of words, type *SSP* 62 No. 7, speed 7.5 cm/sec., self-modulation 9 per sec.

Component	1	2	3	4	5	6
Phase	0	5	7	10	9	8
Volume	3.3	2.9	3.4	10	9	8

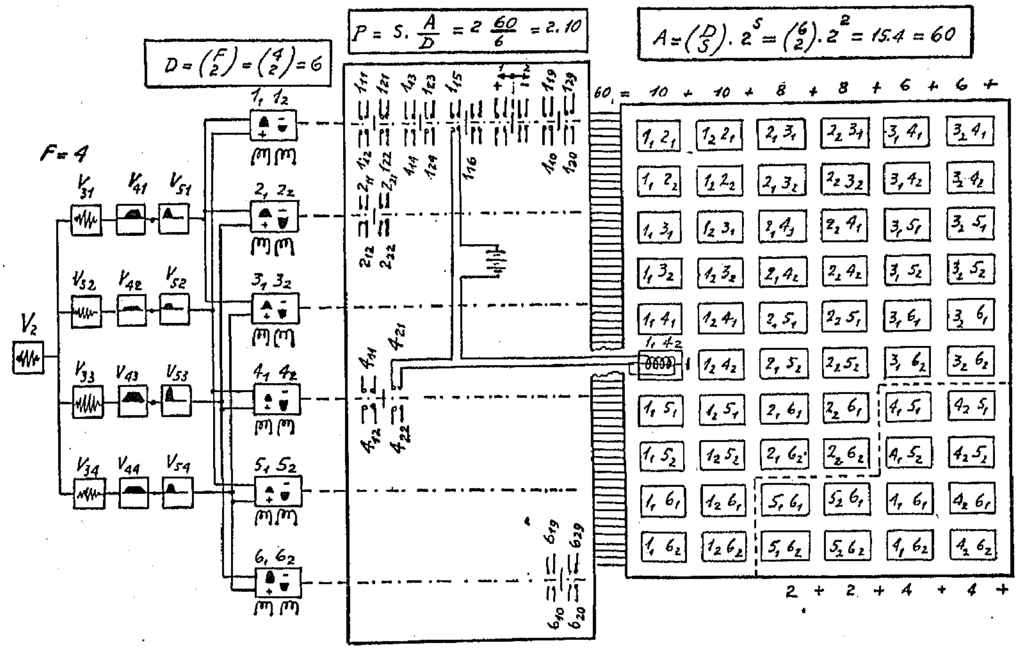

FIG. 19. Schematic diagram of type-sonograph.

the analysis of any part of any sound. Inverse translation of symbols into sounds is not anticipated by the sonograph. But a magnetic tape recording may accompany each sonogram.

Replacing the 6 phonetic filters (100 to 4000 cycles per second) by 6 vocal filters (100 to 400 cycles per second),

$F=$	2	3	4	5	6	7	8	9	10
$\binom{F}{2}=D=$	1	3	6	10	15	21	28	36	45

FIG. 20. Number of differential relays, D, as a function of number of filters, F.

the sonograph would analyze the voice pitch of a speaker or a singer. We can imagine a flexible switching system (automatic or manual) which would modify the sonographic analysis at will, like our brain, which is able to ignore or to notice any part of any sound. Other possible applications are in the different forms of telecommunication or tele-switching. Thus, automatic telephony may be controlled by speaking instead of by dialling or telegrams could be written orally.

It would be superfluous to lengthen the list of possible sonographic applications which are as unlimited as the uses of sounds in general and of words in particular.

	$S=2$	3	4	5	6	7	8	9	10
$D=2$	1 · 4 4								
3	3 · 4 12	1 · 8 8							
4	6 · 4 24	4 · 8 32	1 · 16 16						
5	10 · 4 40	10 · 8 80	5 · 16 80	1 · 32 32			$\binom{D}{S}\ 2^S$ A		
6	15 · 4 60	20 · 8 160	15 · 16 240	6 · 32 192	1 · 64 64				
7	21 · 4 84	35 · 8 260	35 · 16 560	21 · 32 672	7 · 64 448	1 · 128 128			
8	28 · 4 112	56 · 8 448	70 · 16 1120	56 · 32 1792	28 · 64 1792	8 · 128 1024	1 · 256 256		
9	36 · 4 144	84 · 8 672	126 · 16 2016	126 · 32 4032	84 · 64 5376	36 · 128 4508	9 · 256 2304	1 · 512 512	
10	45 · 4 180	120 · 8 960	210 · 16 3360	252 · 32 8064	210 · 64 13440	120 · 128 15360	45 · 256 11250	10 · 512 5120	1 · 1024 1024
12	66 4 284	220 8 1860	495 16 7120						
15	105 4 420	455 8 2640	1365 16 21840						
28	378 4 1512	3276 8 26208	21475 16 343600	98280 32 3144960	376740 64 $24\ 10^6$	$1.2\ 10^6$ 128 $151\ 10^6$	$4.5\ 10^6$ 256 $1.16\ 10^9$	10^7 512 $5\ 10^9$	$2\ 10^7$ 1024 $20\ 10^9$

$$A=\binom{D}{S}\cdot 2^S=\frac{D!}{S!(D-S)!}\cdot 2^S$$

FIG. 21. Number of action relays, A, as a function of number of differential relays, D, and number of contacts in series, S.

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