STUDY OF
AN ADJUSTABLE WAVE-FILTER
SUITABLE FOR
THE RECEPTION OF REFLECTED SEISMIC WAVES

A THESIS

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INTRODUCTION

The present paper has for an object, the description of a wave filter suitable for the reception and selection of the reflected elastic wave with the electromagnetic seismograph.

The practice of " reflection shooting " in seismic prospecting is particularly suitable for outlining salt dome structures, buried anticlines and granite ridges. Consequently the matter is of considerable interest to consulting geophysical and oil producing companies using the seismic method. It is known that several apparatus have been successfully used, for the last four of five years, by the Geophysical Research Corporation,but up to the present time, nothing has been published on the principles involved in the construction of the apparatus or concerning the field practice of reflection shooting.

FOREWORD

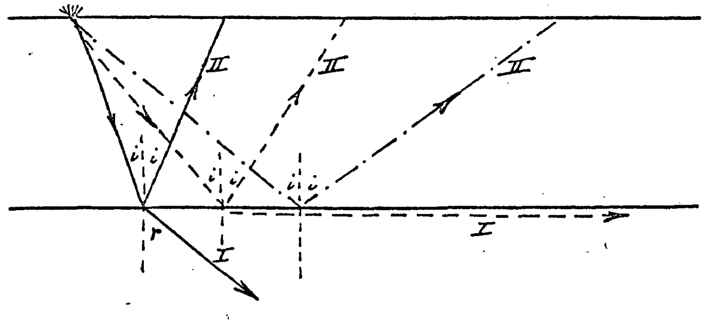
The apparatus here described is based on the frequency characteristics of the reflected seismic waves. These were explained to the writer by Dr. C. A. Heiland of the Colorado School of Mines Faculty, to whom the author wishes to acknowledge his indebtedness. The author also wishes to thank Mr. Dickinson of the Physics department for his help in designing the wave filter, and to Mr. Wantland for useful suggestions in making the photographic records of the performance of the filter.

MAIN DISCUSSION

I : Characteristics of reflected seismic-waves.

a/ Transmission of elastic waves.

Two opinions are generally expressed as to the manner in which artificial elastic waves travel in sedimentary beds. The theory used most widely, in seismic interpretation work holds that the seismic rays or waves, travel in the soil in the same manner as light rays travel in transparent media. When rays from a source of light reach a surface separating two media of different densities, the radiating energy is divided into different parts. One part is refracted according to the law that the ratio of the sines of the angle of incidence (i) and refraction (r) is equal to the ratio of the velocities of the light in the two media $\frac{\sin i}{\sin r} = \frac{V_1}{V_2}$ The other part, therefore, is reflected on the boundary separating the two media. Such a phenomena occurs in seismic prospecting. The seismic energy is reflected to the surface. By recording the time elapsed between the moment of explosion and the moment of arrival of the reflected waves at the seismograph it is possible to determine the depth of the reflecting surface. In practice, considerable difficulty is met with on account of the fact that the receiving seismographs have to be placed at a relatively short distance from the shot point in order to receive sufficient reflected energy. Theoretically, the maximum energy will be received when the receiver is at a distance from the shot point such that the sine of the angle of incidence equals the ratio of the velocities in the two media considered, that is when the angle of incidence is equal to the critical angle.



I : Refracted wave

II: Reflected wave

Fig. 1

For such a condition it is obvious that the disturbance travelling directly from the shot point to the receiver along the surface will arrive at the receiver ahead of the reflected seismic waves. A sharp indication of the time of arrival of these waves is impossible unless the surface wave is eliminated.

The second theory holds that the law of refraction of seismic rays does not exist. According to Schweydar the transmission of artificial elastic waves is due to oscillations of layers as a whole. The strata are individually set vibrating, by the explosion. Vibrations are set up in each one of the layers at the point of intersection of the perpendicular line from the shot point to the surface of stratification and spread circularly from these points. The overlying beds are subjected to forced vibrations the period of which is the period of underlying ones. Thus the vibration movements of the deeply buried layers may be received at the surface at any distance from the shot point. In other words reflected and refracted waves do not exist. Waves from a high speed bed received near the shot point (after elimination of the surface waves) and waves received at considerable distance are due to the same physical phenomena, namely oscillation of individual layers.

According to Kölher, the natural period of oscillation, T, of an individual layer is given by the following formula. $T = \frac{1}{4vd}$ in which v is the velocity of propagation of the longitudinal waves therein and d the thickness of oscillating layer. The fundamental frequency of the wave set up as given by the above formula shows a certain number of harmonics, the ratio of their frequencies being as successive uneven numbers. Both fundamental and harmonic frequencies are identified at the surface as reflected waves. It is easily shown from the formula that their frequencies increase with the thickness and the square root of the Young modulus of the formation and decrease with the square root of the density.

So far as the author knows there is no published data on the frequencies of reflected elastic rays. From experiments carried on by Mothes in order to determine the thickness of the " Glacier du Vent " in the Alps by the reflection method, it can be inferred that the frequencies of the reflected waves vary between 80 and 100 cycles per second. The frequency through the ice varies between 20 and 40 cycles a second. As the number of impulses received depends on the type of instrument used and varies with its natural period, no absolute information can be derived from seismic record obtained with an undamped seismograph which is the usual case with the electromagnetic type. Mothes was using a vertical Mintrop Seismograph damped with oil; thus some degree of reliability can be placed on the above determination of frequencies.

As a matter of fact the frequencies of the reflected waves received depends on the nature of the two media at the boundary of which the reflection takes place, on the thickness of the upper formation and on the distance between the shot point and the receiving station.

According to Dr. Heiland, the surface waves have always a lower frequency than the reflected waves. The natural ground unrest has usually a frequency less than 15 cycles a second and the longitudinal waves travelling along the surface may have a frequency as high as 50 cycles a second. The latter will have a higher frequency when the surface formation is more consolidated.

b/ Conditions favorable for reflection shooting.

From the preceding discussion it can be derived that the favorable geologic condition for the use of reflection shooting is the presence of a low speed bed above one of high speed. There must be an abrupt change between the two media. This condition may be expressed better by saying that an abrupt change must take place with depth in the specific acoustic resistance of rocks.

c/ Requirement for a seismograph for reflection shooting.

The seismic record obtained in reflection shooting must show a sharp indication of the arrival of the reflected waves. As the surface waves always arrive at the receiver before the reflected waves, they must be eliminated. The seismic surface wave consists of a group of frequencies whose range is below 50 cycles a second and varies according to the geologic surface conditions.

The reflected wave is a group of higher frequencies and being the impulses on which the method is based, the full range of frequency must be shown unattenuated on the record.

The receiver must therefore have an adjustable admitted frequency range and must be tuned to receive the higher frequencies. It must be borne in mind that series, or parallel tuned circuits, would not be very effective in eliminating frequencies as the resonance peaks of such circuits are very broad at low frequencies. The process of elimination that the author suggests is based on the principle of " wave-trap " or " wave-filter " as they are known in telephone circuits.

In the particular problem of receiving the reflected wave, a " high pass wave-filter " is used the characteristic of which is to let pass the frequency range above a definite cut-off frequency.

II : Calculation of a High Pass Wave-Filter.

a/ General considerations.

A high pass filter is represented in Fig. 2 and is composed of two condensers c in series and an inductance L across the transmission line.

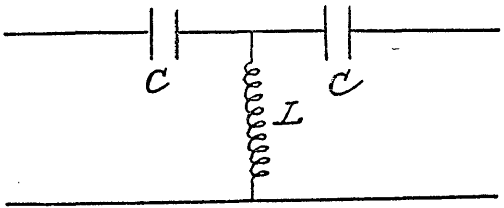


Fig. 2

A condenser will pass currents of high frequency much easier than currents of low frequency. The capacity of this condenser is selected of such a value as to allow passage of frequencies above the desired cut-off point and to hinder the flow of frequencies below this point. It is desired to return all frequencies lower than the critical point to the source of current which is the geophone in the particular case considered here. To accomplish this an inductance coil L is used for a by pass as shown on Fig. 2. An inductance will allow comparatively free flow of low frequencies through it while offering great opposition to higher frequencies. The inductance of this coil is of such a nature that it carries the frequencies below the cut-off point, but rejects the higher frequencies which are thus forced to pass on through the circuit. It should be understood that the effectiveness of any filter will be improved if duplicates of filter sections as shown in Fig. 2 are inserted into the line from the seismograph on to the recorder. Since the cut-off points of coils and condensers are not sharply defined it is necessary to build a high pass filter of repeated sections if it is to be reasonably effective in its work.

b/ Inductance Coil Requirements.

In order that no dissipation takes place in the filter the ratio $\frac{R_L}{\omega L}$ should be less than 2 %. RL is the D.C. resistance of the coil, L its inductance and $\omega = 2\pi f$ the angular velocity of the vector current at the cut-off frequency. Such requirements at low frequency are very exacting because:

1. Large inductances are needed in order that the value of the condensers on the line be practicable.
2. Iron-core inductances must be used for which the value of the inductance is variable with the intensity, of the a.c. and d.c. currents.
3. The value of the inductance is variable with the frequency.

In order to measure inductances the writer uses the following method which is represented on fig. 3. The rheostat 1 is inserted in the light circuit giving normally 110 volts and 61.7 cycles per second.

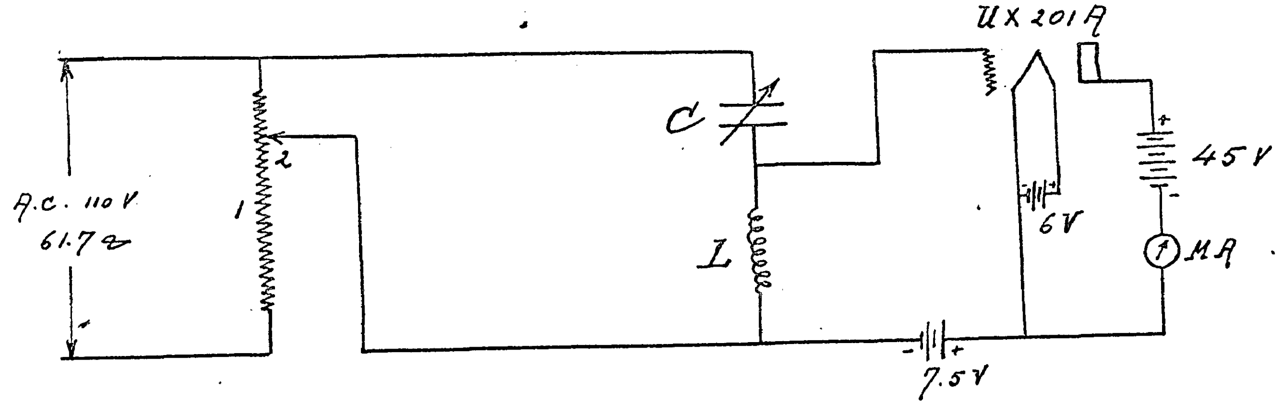


fig. 3

By means of the sliding contact (2), an electromotive force is fed in the circuit composed of the adjustable condenser C and of the choke coil L, the inductance of which is to be determined. The a.c voltage across the coil, L, is fed in the grid circuit of a U.X.201CA vacuum tube biassed to zero current in the plate circuit by means of a 7.5 volt dry cell. A step adjustment of the condenser, C, gave the following readings of the plate current of the tube on the D.C. milliameter. The determinations were made for four different coils, the results are plotted on graphs I, I_a and I_b.

Capacity in ufd.	Thordarson Coil no.1 M.A.	30 Henries Thordarson Choke Coil M.A.	Coil I M.A.	Coil II M.A.
0.1	0.05	0.15	0.1	0.1
0.2	0.1	3.4	0.1	0.1
0.3	0.5	4.6	0.2	0.15
0.4	2.7	3.65	0.35	0.25
0.5	3.95	2.8	0.85	0.45
0.6	4.8	2.25	2.2	1.2
0.7	4.75	2.00	3.65	2.55
0.8	4.7	1.75	4.25	3.4
0.9	4.5		4.35	3.65
1.0	4.35	1.5	4.30	3.6
1.1	4.1	1.4	4.1	3.4
1.2	3.85	1.35	3.8	3.15
1.3			3.45	2.95
1.4			3.15	2.75
1.5	3.35	1.2	2.95	2.55
1.7			2.5	2.25
2.0	3.0	1.1	2.15	1.9
2.5			1.7	1.6
3.0	2.5		1.5	1.35
4.0	2.3		1.2	1.1
5.0	2.1		1.1	1
6.0	2.0		1	0.95

Table 1

The resonance point is attained where the capacity of the condenser, C, is respectively 0.6, 0.24, 0.9 and 0.9 microfarads. From the formula $f = \frac{1}{2\pi\sqrt{LC}}$ giving the relation between the frequency, the capacity and the inductance of a serie resonant circuit it is derived that the inductances given by $L = \frac{1}{4\pi^2 f^2 C}$ are respectively 11.1; 27.6; 7.4 and 7.4 henries.

The discrepancies in the value of the 30 henries choke coil probably come from the fact that no intermediate capacity was introduced in the circuit between 0.2 and 0.3 microfarad. After several trials with the coils at the disposal of the author it was found that the 30 henries choke coil was the most satisfactory as it is possible with a condenser of 7 microfarads capacity, to lower the cut-off frequency to about 8 cycles a second. Accordingly the following calculation were made for a filter built with a 30 henries coke coil.

c/ Calculation of the Filter.

The calculation of wave-filters is based on the theory of infinite artificial transmission lines which are represented by serie and parallel impedances across the line as shown in fig. 4. The n -1, n and n + 1 sections are considered. Z_1 and Z_2 are almost pure reactances, the small resistances necessarily associated with inductances being practically negligible in its effect on the filter properties when the ratio $\frac{R_L}{\omega L}$ is smaller than 0.02 at the cut-off frequency.

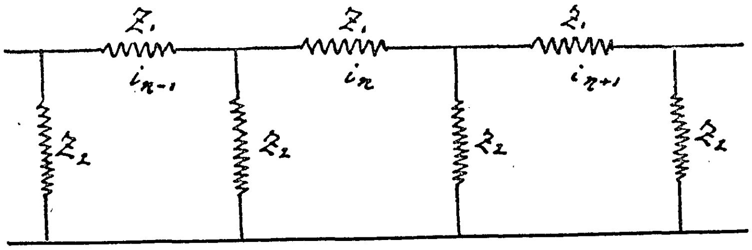


fig. 4

When a steady state is established, the current of frequency f is sinusoidal and of the form $i_n = I_n \sin (ft - \phi n)$ where i_n is the instantaneous current in the n^{th} section and the I_n the maximum amplitude. ϕn is the phase angle.

In practice, the filter has a limited number of meshes and is terminated by a mid-serie impedance. The filter may be considered as composed of a number of sections of the type shown on figure 5. If the line is continued with similar sections indefinitely to the right, the measurement of the inductance across AB or across CD will give the same result, K, then replacing the infinite network by an impedance K across CD,

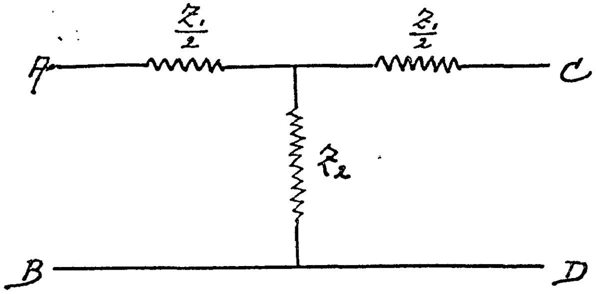


fig. 5

the impedance across AB is given by the following expression:

$$K = \frac{Z_1}{2} + \frac{Z_2\left(\frac{Z_1}{2} + K\right)}{Z_2 + \frac{Z_1}{2} + K}$$

Then $$K = \sqrt{Z_1 Z_2 + \frac{Z_1^2}{4}}$$

In the particular case of a high-pass filter

$$Z_1 = -j\frac{1}{2\pi f C}$$

$$Z_2 = j\,2\pi f L$$

Where $j = \sqrt{-1}$

Then $$K = \sqrt{-\left(j\frac{1}{2\pi f C}\right)\left(j\,2\pi f C\right) + \frac{\left(-j\frac{1}{2\pi f C}\right)^2}{4}}$$

or $$K = \sqrt{\frac{L}{C} - \frac{1}{16\pi^2 f^2 C^2}}$$

The frequency which makes the above expression equal zero is called the cut-off frequency. As will be seen later, the reactance below the cut-off frequency is a pure impedance and above, a pure resistance.

As the inductance, L, is 30 henries, if we want to cut-off at 50 cycles a second, we derive that the capacity of the mid-serie impedance $\frac{Z_1}{2}$ is:

$$2C = \frac{2}{16\pi^2 50^2 \times 30} = 0.169\ \mu fd.$$

It is more convenient to use a condenser of 0.2 μfd then the cut-off frequency will be:

$$f^2 = \frac{2 \times 10^6}{16\pi^2\, 0.2 \times 30}$$

$$f = 46$$

When the frequency of the current impressed across the filter is less than 46 cycles per second the total impedance K_1 of the filter is imaginary and the system acts as a pure inductance, the value of which is the infinity for zero frequency or D. C. current.

For frequencies above 46 cycles a second the filter acts as a pure resistance. The calculated values of K for the filter system shown on fig. 6 are recorded in on the following table and plotted on graph II

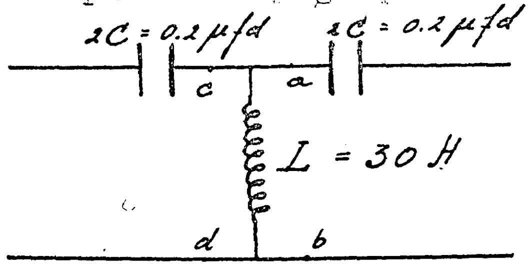


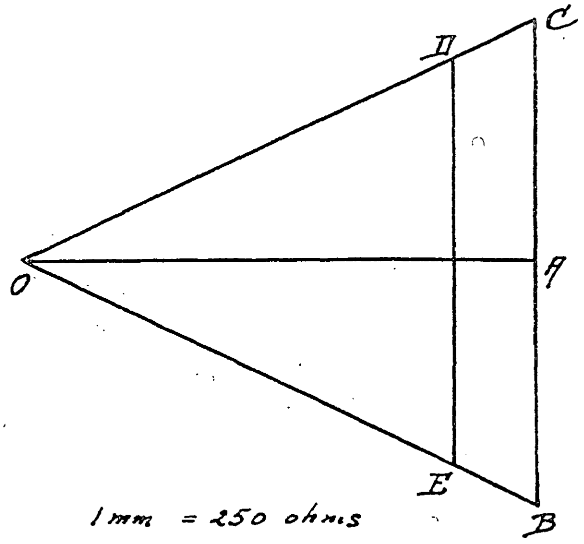
fig. 6

Table II

Frequency	$K = 10^4 \sqrt{3 - \frac{6350}{f^2}}$
0	
10	77000
20	35850
30	21500
40	9850
46	0
50	6780
60	11300
70	13050
80	14150
90	14850
100	15370
110	15730
120	15950
130	16200
140	16350
150	16500
	17300

d/ Vector diagram of the filter.

Let us consider the filter of fig. 6 for which we have just calculated the characteristic impedance working at 100 cycles in an output resistance of 15370 ohms. The output resistance is represented to scale on figure 7 by a horizontal vector, OA. We have in serie with it a capacity of 0.2 μfd which offers to the a.c. current of 100 cycles an impedance of $\frac{10^6}{2\pi \times 0.2 \times 100} = 7980$ ohms which is represented by the vector, AB, as the effect of a capacity is to throw the current ahead of the electromotive force. The effect of the output resistance and the capacity is the same as if an impedance, OB, was put across ab. The latter is added in parallel to the reactance of the choke coil which is $2\pi \times 100 \times 30 = 18850$ ohms. The resulting impedance across cd is given by:



1 mm = 250 ohms
1 mm = 10^{-4} mhos

fig. 7

$$\frac{1}{\text{Impedance } cd} = \frac{1}{OB} + \frac{1}{2\pi f L}$$

$\frac{1}{OB}$ is represented by the vector, OD

$\frac{1}{2\pi f L}$ is represented by the vector, DE

The resultant vector of OD and DE is the vector, OE, which is the reverse of the total impedance of the choke coil, the condenser and the output impedance. To the vector, OC, the vector, CA, representing the capacitance of the other condenser is added. It is seen that the diagram is closed and that for a proper operation of the filter, it is necessary that the input impedance equals the output impedance. Similar diagrams may be repeated for varying frequencies.

e/ Characteristic of the high-pass wave filter.

Attenuation constant and phase constant.

The attenuation band of the filter system is the band of frequencies for which the characteristic impedance of the line is imaginary.

In the general theory of transmission lines(1) the relation between the input voltage Vi and the output voltage Vo is given by $V_o = V_i \; e^{-\theta}$

Where θ is the propagation constant of the line. θ is a complex quantity of the form $\alpha + j\beta$ where α is the attenuation constant and β is the phase constant.

Then $V_o = V_i \; e^{-\alpha} \times e^{-j\beta}$ which shows that the output voltage Vo is reduced in magnitude by the factor and that it is lagging in phase by an angle β.

After Bartlett, θ in function of the constants of the filter for a single section is given by

$$\cosh \theta = 1 + \frac{\frac{Z_1}{2}}{Z_2}$$

In the filter considered on fig. 6,

$$\frac{Z_1}{2} = -j \frac{1}{2\pi f (2C)} = -j \frac{10^6}{2\pi f (0.2)}$$

$$Z_2 = +j \, 2\pi f L = +j \, 2\pi f \, 30$$

Thus the propagation constant θ for different frequencies is given by:

$$\cosh \theta = \cosh(\alpha + j\beta) = 1 - \frac{10^6}{4\pi^2 f^2 \, 0.2 \times 30}$$

which shows that $\cosh \theta$ is real for the complete range of frequencies.

Note:(1) A.C.Bartlett - The theory of Electrical Artificial Lines and Filters. John Wiley and Sons - 1930

As $\cosh\theta = \cosh\alpha\cos\beta + j\sinh\alpha\sin\beta$ then the quantity $\sinh\alpha\sin\beta = 0$

Thus $\sinh\alpha$ or $\sin\beta$ must be zero.

a/ $\beta = 0$: then $\cosh\theta = \cosh\alpha = 1 - \frac{10^6}{4\pi^2 f^2 0.2 \times 30}$

and the attenuation constant α is given by:

$$\alpha = \cosh^{-1}\left(1 - \frac{10^6}{4\pi^2 f^2 0.2 \times 30}\right)$$

b/ $\beta = \pi$: then $\cosh\theta = -\cosh\alpha$

and $\alpha = \cosh^{-1}\left(\frac{10^6}{4\pi^2 f^2 \times 0.2 \times 30} - 1\right)$

c/ $\alpha = 0$: then $\cosh\theta = \cos\beta$

and $\beta = \cos^{-1}\left(1 - \frac{10^6}{4\pi^2 f^2 0.2 \times 30}\right)$

It is easily seen from the preceding formulae that when the attenuation constant α is zero, the phase shift β decreases from π to 0 for an increase in frequency. When the phase difference β is constant and equal to π, the attenuation constant α decreases from infinity to zero when the frequency increases from zero to the cut-off frequency. The results computed from the formulae a, b and c are shown in Table III and graphically represented on graph III.

Table III

Frequency f	Cos h θ	Attenuation constant	Phase difference β in radians.
0	$-\infty$	∞	π
10	- 41.5	4.419	π
20	- 9.62	2.954	π
30	- 3.73	1.991	π
40	- 1.66	1.093	π
46	- 1.	0	π
50	- 0.7	0	2.3475
60	- 0.118	0	1.6901
70	0.132	0	1.438
80	0.335	0	1.229
90	0.475	0	1.076
100	0.575	0	0.958
110	0.649	0	0.864
120	0.705	0	0.788
130	0.749	0	0.724
140	0.783	0	0.671
150	0.811	0	0.642
	1	0	0

Calculation of the adjustable filter.

In practice it will be found convenient to eliminate at will the frequency range from 0 to 50, 0 to 25 and 0 to 10 cycles per second or steps of approximately the same magnitudes, because of the fact that the frequency range of the surface waves is not definite and varies with the constitution of the surface and underground formations. Further more, the unconsolidated sediments covering the reflecting surface may be of such a thickness that the higher frequencies of the group of reflected waves may have been absorbed. Consequently the cut-off frequency of the filter must be adjustable.

The filter designed by the writer is made to be used with different coils of which the measurements of the inductances have been indicated above. A maximum number of adjustable steps with the minimum number of condensers has been sought in the construction.

The disposition used is represented on figure 8.

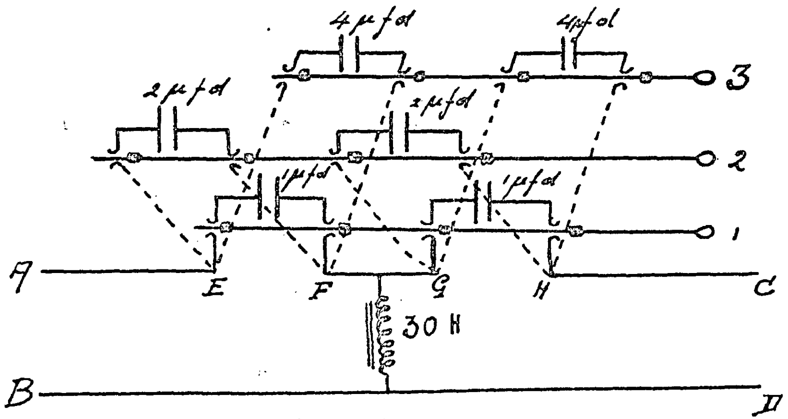


fig. 8

A, B, C and C are the binding posts to which the trans-ission line is connected. Two sets of condensers of 1, 2 nd 4 microfarads capacity are disposed in such a way that they an be inserted separately or simultaneously into the line by eans of the sliding switches 1, 2 and 3. The following com-inations are possible:

Switch 1 in : 1 ufd condensers are in the line
" 2 " : 2 " " " ----------
" 3 " : 4 " " " ----------
" 1 and 2 in : 3 " " ---------------
" 1 and 3 " : 5 " -------
" 2 and 3 " : 6 " -------
" 1, 2 and 3 in : 7 " ----------

The corresponding cut-off frequencies calculated by the ormula:

$$f^2 = \frac{2 \times 10^6}{16\pi^2 C \times 30}$$

re; 20.6; 14.55; 10.3; 11.9; 9.2; 8.4 and 7.78 cycles per econd. In order that the cut-off frequency 46 be available t will be necessary to connect two condensers of 0.2 ufd inding posts E, F, G, H on fig. 8.

The cut-off frequencies available by making use of the hree types of coils are tabulated in table IV.

Table IV

Capacity of condensers in the line	L = 30 Henries	L = 11.1	L = 7.4
1	20.6	33.8	41.4
2	14.55	23.95	29.3
4	10.3	16.9	20.7
3	11.9	19.55	23.9
5	9.2	15.65	18.55
6	8.4	13.8	16.9
7	7.78	12.8	15.65

Filter Test

The above cut-off frequencies can not be taken as exact as the sharpness of the cut-off point depends on the accuracy with which the inductance of a choke coil is known and such a factor is very difficult to determine accurately. Furthermore, as stated in the preceding pages the inductance of a choke coil with iron core, depends on the intensity of both the d.c. and a.c current flowing through the coil and on the frequency.

Thus it was necessary to verify how close the theoretical absorption of the filter was approximated in practice.

The attenuation of a range of frequencies varying from 7.93 to 41.8 cycles per second by the filter section shown on figure 9 was actually performed by the author by means of the apparatus described in the following pages. The frequency range was obtained by means of the generator represented on fig. 10 which was specially designed and constructed by Mr. Hull in the prescision instrument shop at the School of Mines in order to give an alternating current of the order of the one received from an electromagnetic type of seismograph. A horizontal shaft, A, is coupled by means of the elastic coupling, B, to a synchronism motor, C, whose characteristics are the following:

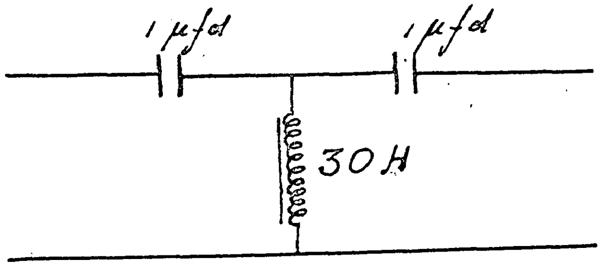


fig. 9

Number of turns per second	1800
Power	1.6 H.P.
Current	7.5 amp.
Voltage	110 volts

On the horizontal shaft A the sliding wheel, D, makes act by means of a leather disc with a horizontal aluminum isc, E. By sliding the wheel, D, on the edge of the inum disc the latter makes approximately 8 revolutions second. On the vertical shaft, F, is fixed the coil G n revolves inside the Helmolz coil H. The Helmolz coil ng a constant and uniform magnetic field, the output ne coil G at the binding posts, I and J, will be a very ar alternative current which will be recorded by the llograph as an exact sine curve.

The general hook-up for recording the performance of ilter is shown on fig. 11.

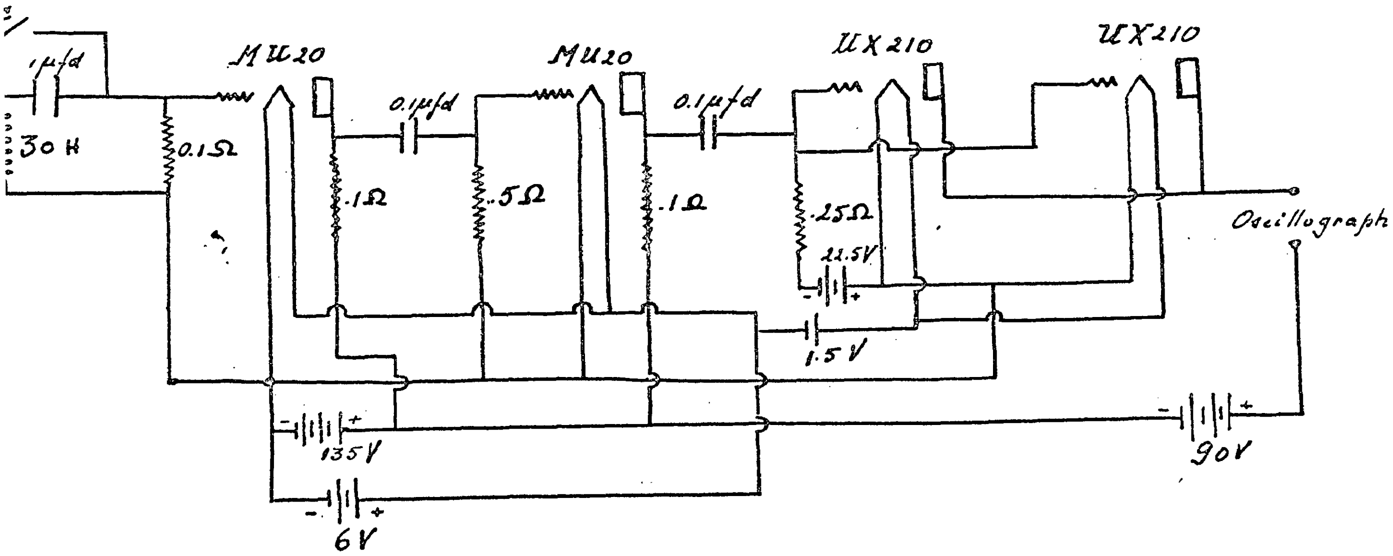


fig. 11.

The current obtained at the onput of the generator fig. 10) was introduced in the filter at AB and from there was amplified in the four stages resistance amplifier shown on figure 11. The output of the amplifier was passed through a General Electric Oscillograph of great sensitivity. The light from a Schweydor seismagraph recorder was condensed by means of a converging lens on the moving mirror of the galvanometer and reflected back on a moving photographic film. The pictures obtained for different frequencies are shown in fig. 12.

An accurate determination of the frequency is possible by means of the time mark at the bottom of each picture. The unattenuated part of the curve shown at the left of each diagram is obtained by cutting the filter off the line by means of the switch C of fig. 11. Then the filter is introduced in each diagram at the time marked by an arrow. It is noticeable that for the lowest frequencies a considerable absorption takes place whereas for higher frequencies no attenuation actually occurs. From the diagrams of fig. 12, the determinations recorded in table V were made.

Table V

'requency	Amplituce Filter out	Amplitude Filter in	Attenuation		
			Actual	Theoretical	
				α	$e^{-\alpha}$
7.93	16	0.8	0.05	3.21	0.04
8.8	17.2	1.	0.058	2.98	0.05
10.85	20.8	2.	0.0962	2.51	0.08
13.4	25.8	4.	0.155	1.99	0.135
15.85	31	6.7	0.216	1.51	0.22
17.5	30.7	8.2	0.267	1.17	0.31
19.05	31.5	13	0.413	0.81	0.445
20.4	37.3	15	0.402	0.28	0.756
26.8	34.1	31	0.907	0	1
29.6	41	41	1	0	1
34.25	36	37	1.027	0	1
41.8	43.8	44	1.005	0	1

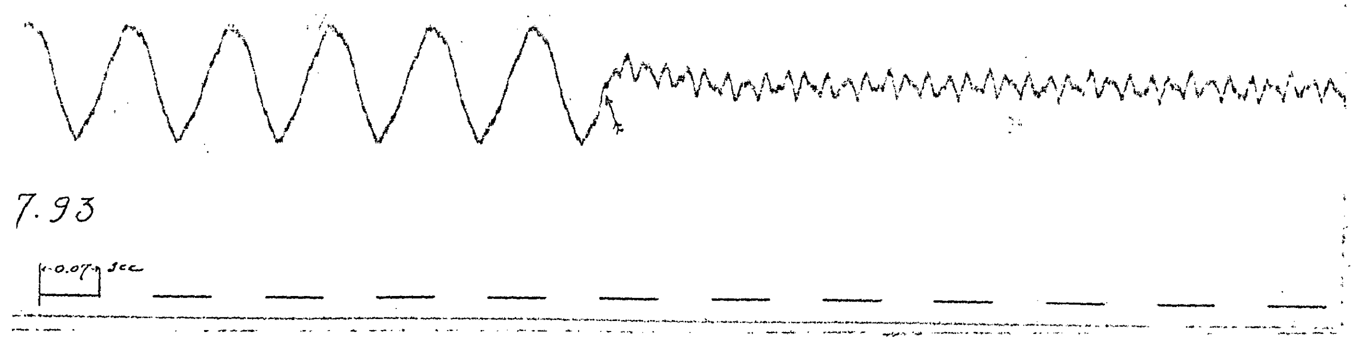
The column of actual attenuation is obtained by making he ratio of the amplitude with filter in to the amplitude hen the filter is out.

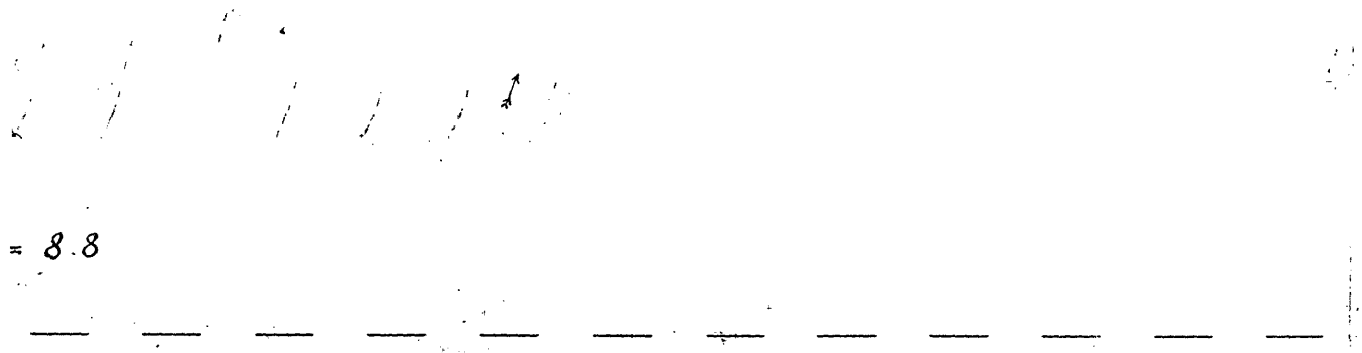
The column of theoretical attenuation is obtained by calulation of the attenuation constant by the formula:

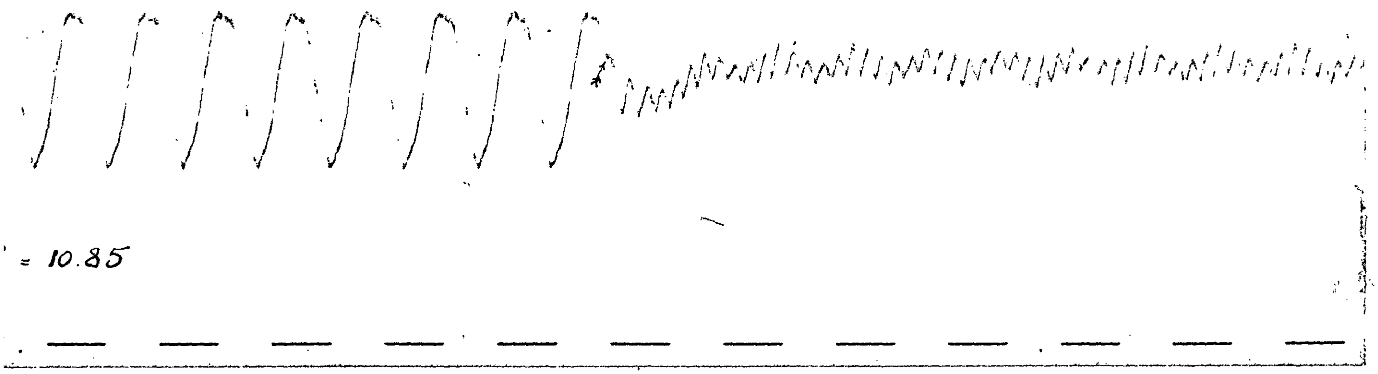
$$\alpha = \cosh^{-1}\left(\frac{10^6}{4\pi^2 f^2 \times 1 \times 30} - 1\right)$$

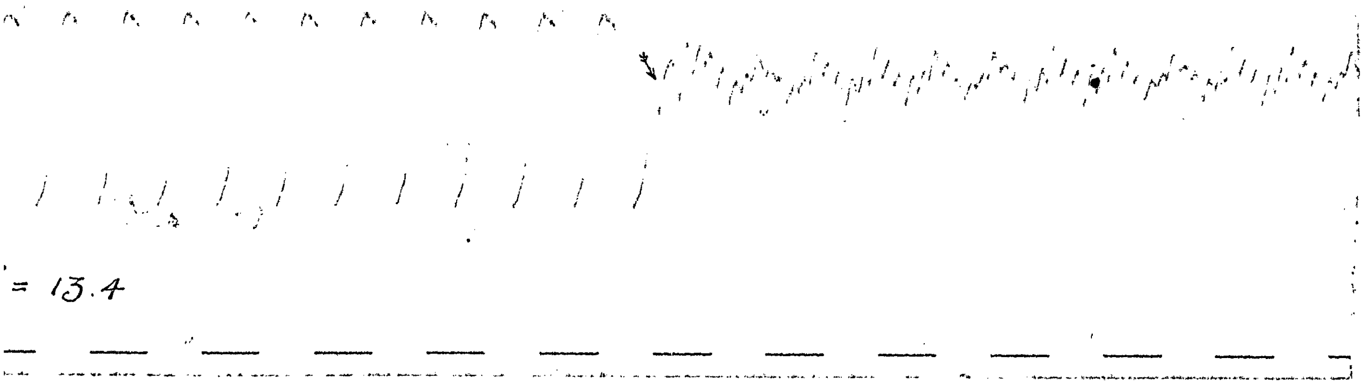
n the attenuation band that is for the range of frequencies rom 0 to 20.6 the theoretical cut-off frequency. The theoreical attenuation is obtained by the expression $e^{-\alpha}$ which is omputed in the last column of table V.

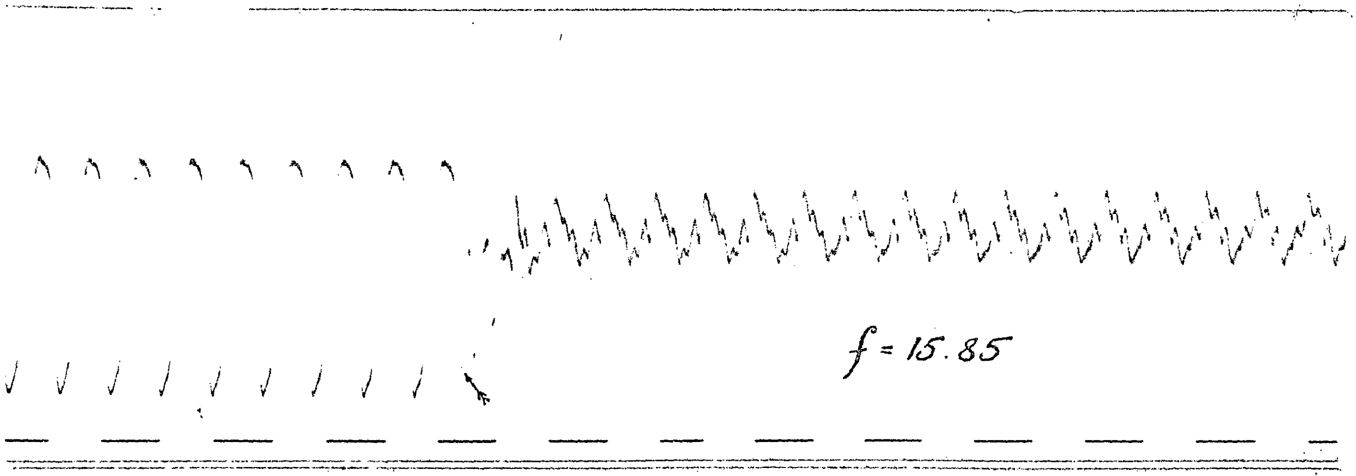
It is noticeable that the actual cut-off frequency is very


7.93
0.07 sec

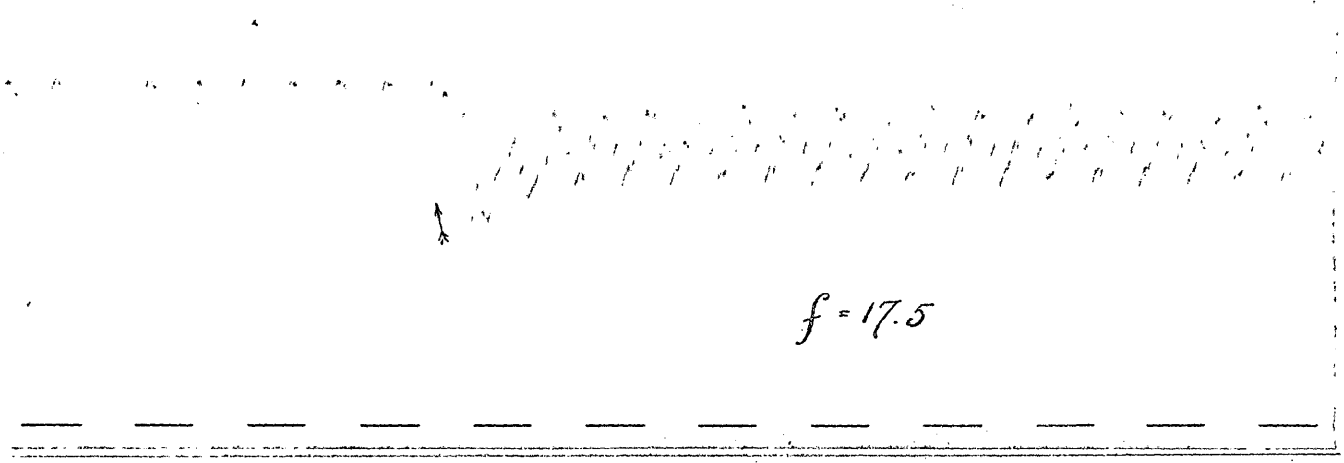

= 8.8


= 10.85

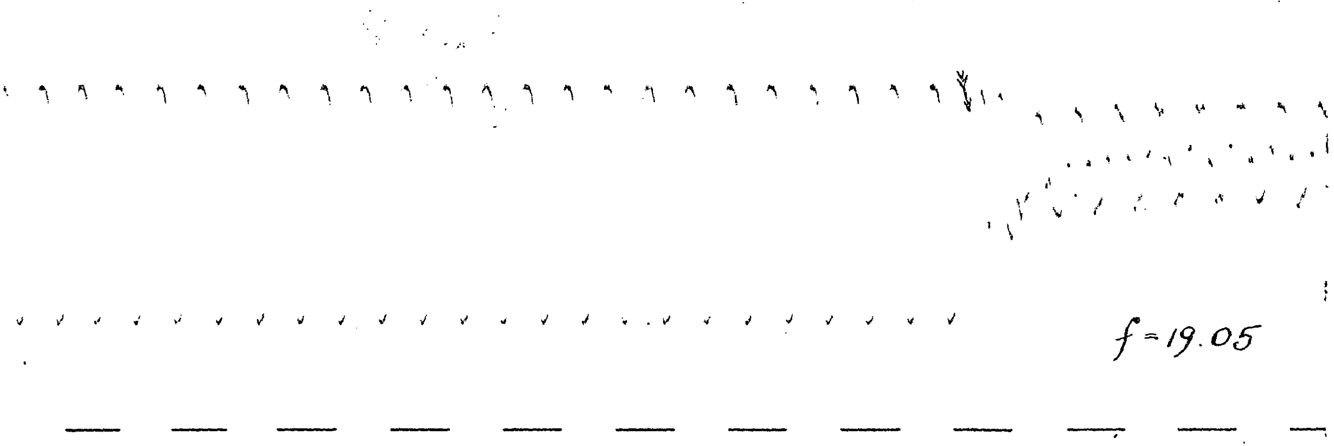

= 13.4



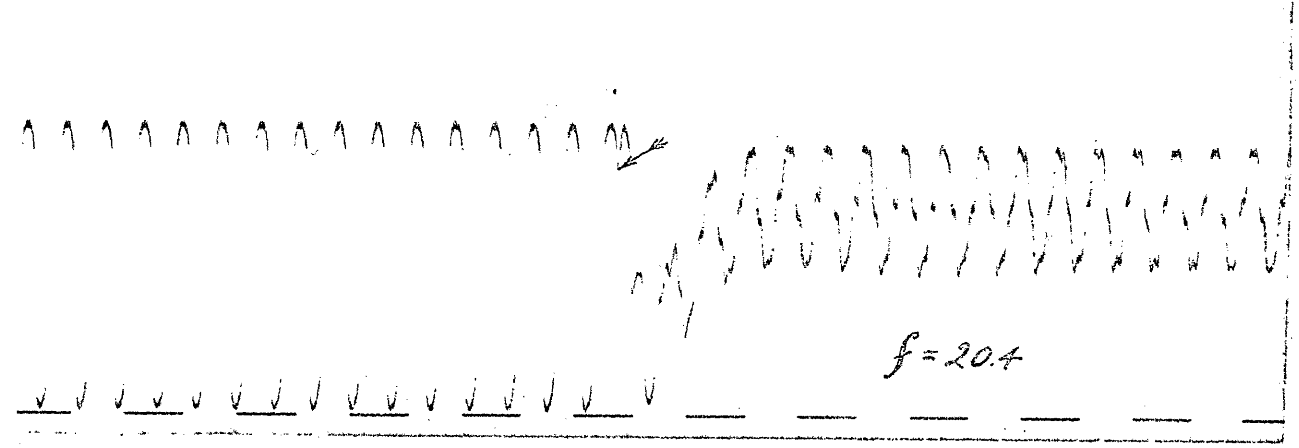
f = 15.85



f = 17.5



f = 19.05



f = 20.4

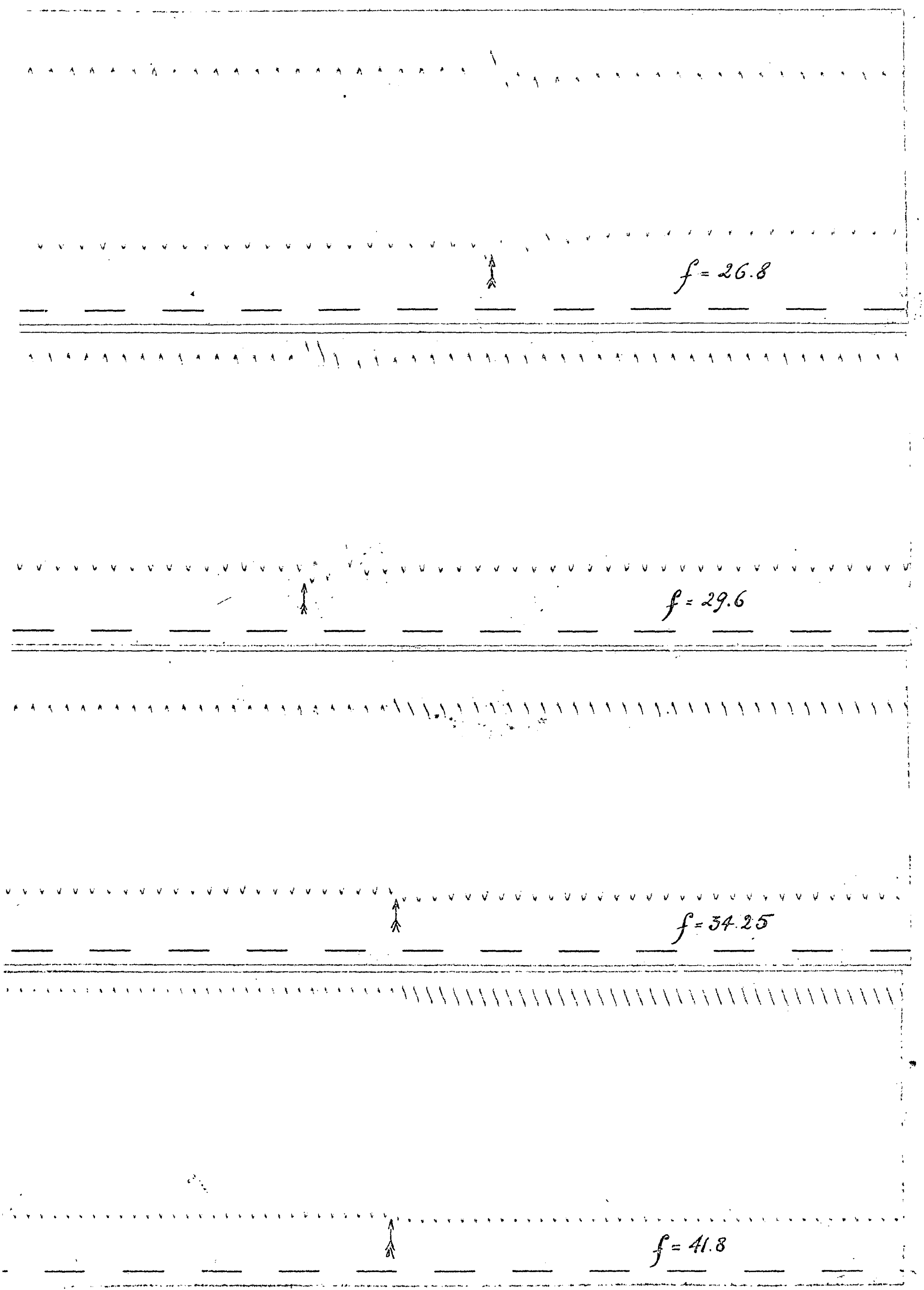
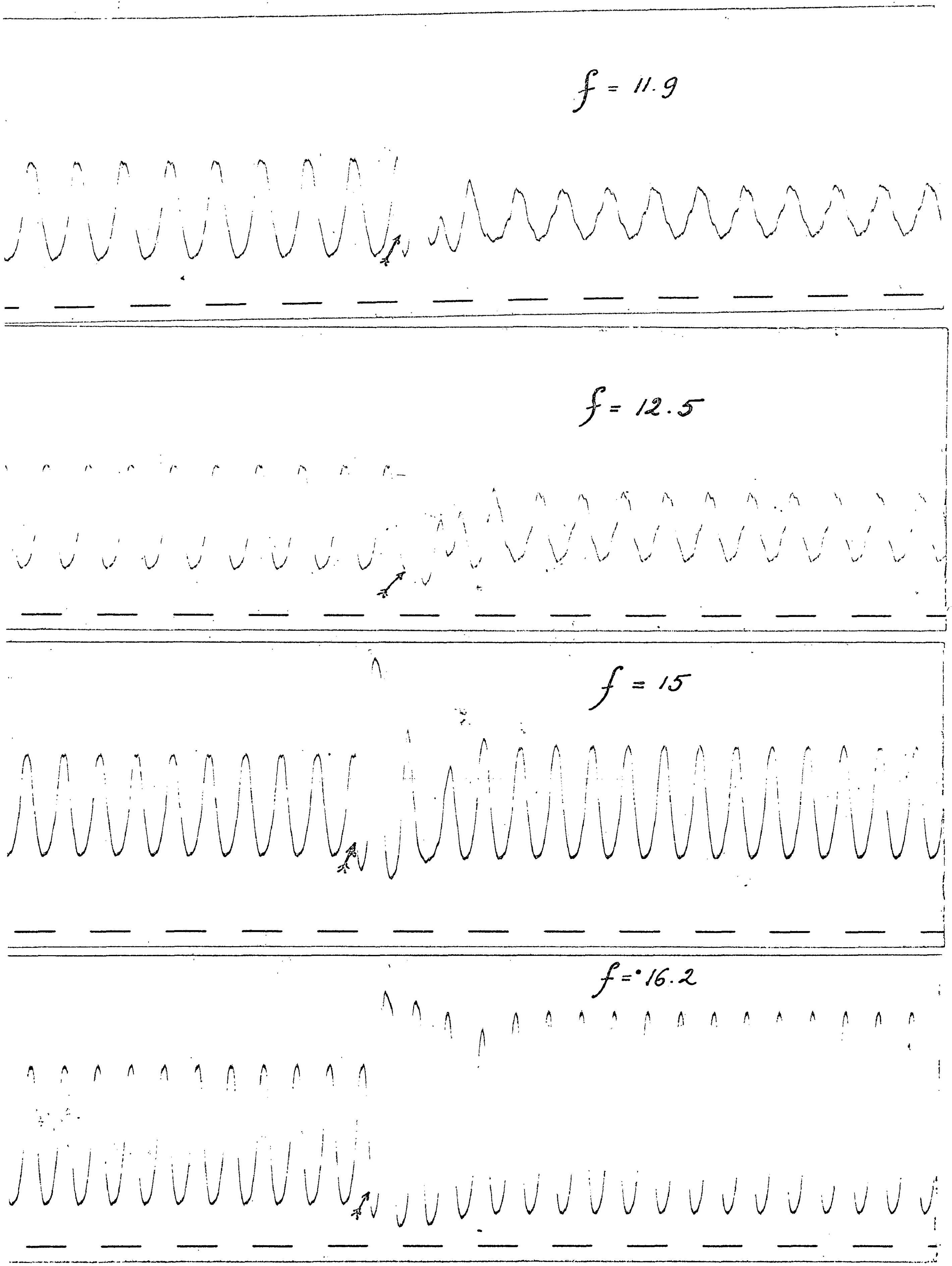
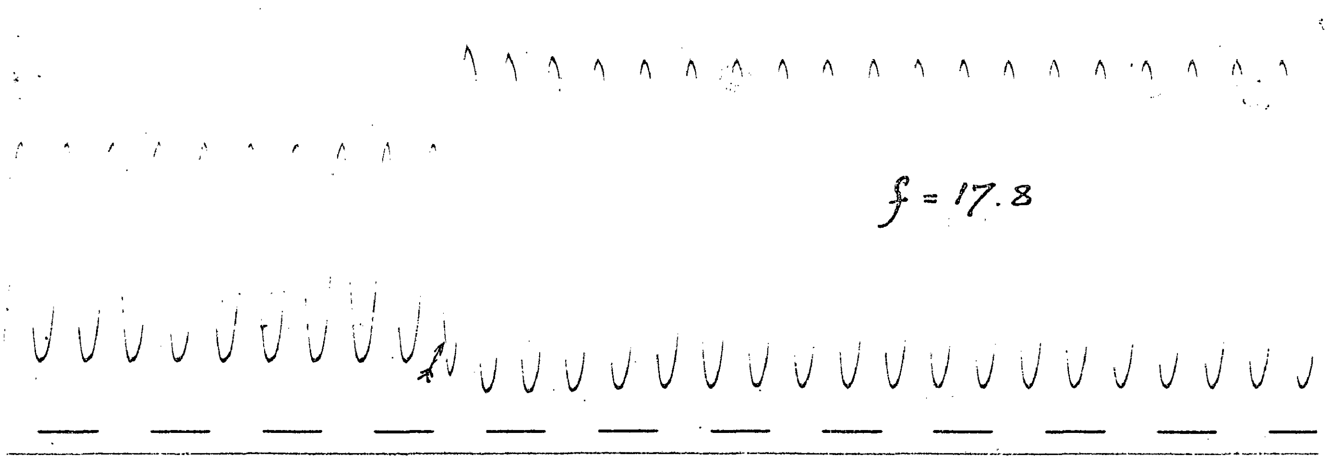
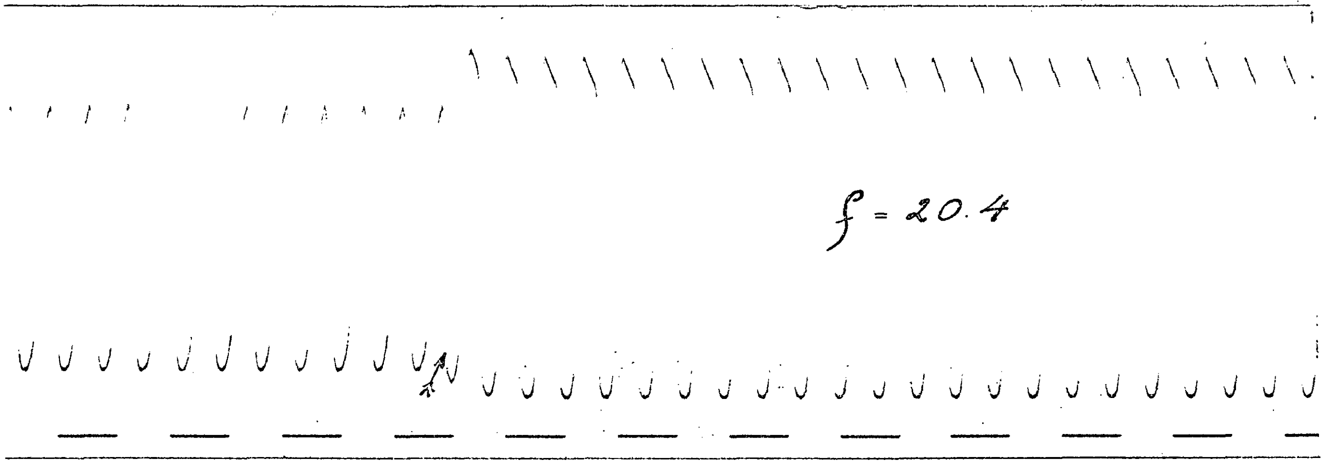
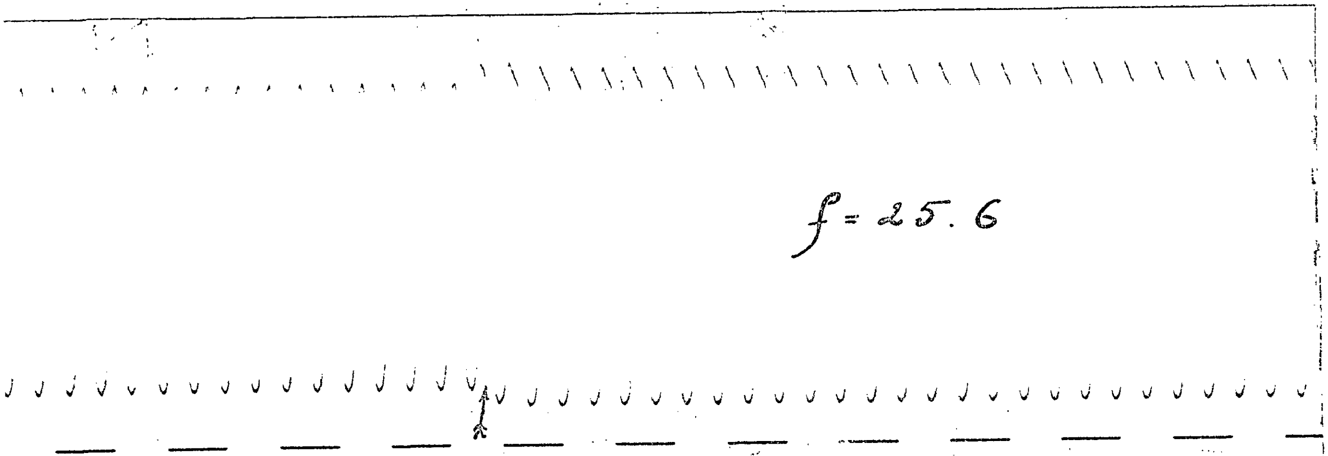

f = 26.8
f = 29.6
f = 34.25
f = 41.8

Fig 14




f = 17.8


f = 20.4


f = 25.6

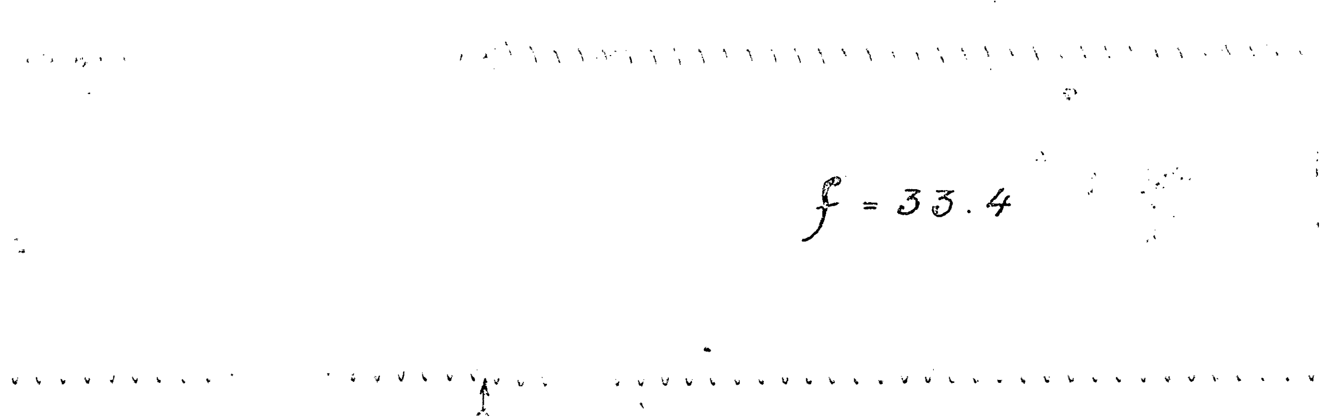

f = 33.4

Table VI

F	K	$-\beta$	Voltage ratio	
			Theoretical	Actual
11.9	1950	119°20'	2.05	0.525
12.5	2200	110°40'	2.78	0.667
15	2820	86°20'	14.3	1.1
16.2	3000	78°40'	5.04	1.435
17.8	3160	70°20'	2.73	1.51
20.4	3340	60°20'	2.01	1.285
25.6	3550	47°20'	1.47	1.1
33.4	3690	35°40'	1.23	1.03

As may be observed from the diagrams of fig. 14 the practical cut-off frequency is situated between 12.5 and 15 cycles a second, instead of being 10.25 cycles a second. This may be accounted for by the inaccuracy with which the inductance of the coil is known. It is also observed from table VI that the theoretical voltage ratio $\frac{V_n}{V_o}$ is much larger than the actual for the frequency range from 15 to 30 cycles a second. This may be explained by the fact that the saturation current of the amplifier tubes is reached, thus the output plate current of the last stage of the amplifier is not exactly proportional to the input voltage.

Conclusion

The applicability of the properties of wave filters to e practice of the seismic method of prospecting by reflection s been demonstrated on the preceding pages. This is not the ly application it might have in the field of geophysical ospecting by the seismic method. Filters may be used for e elimination of the ground unrest and thus permit a more curate determination of the time of arrival of the seismic ves together with the advantage of reducing the amount of namite. It is known that the amount of dynamite to be shot a station depends on the depth to be attained together with e amount of ground unrest present. By using a low pass filter th sufficiently low cut-off frequency, the ground unrest will eliminated.

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