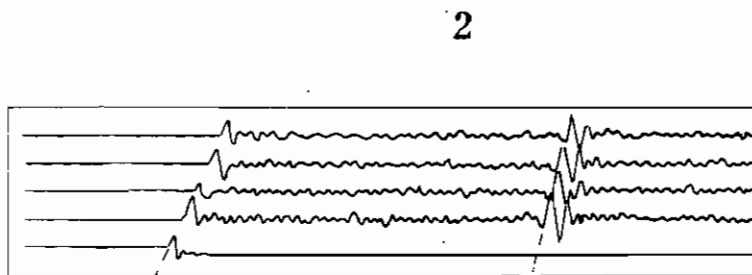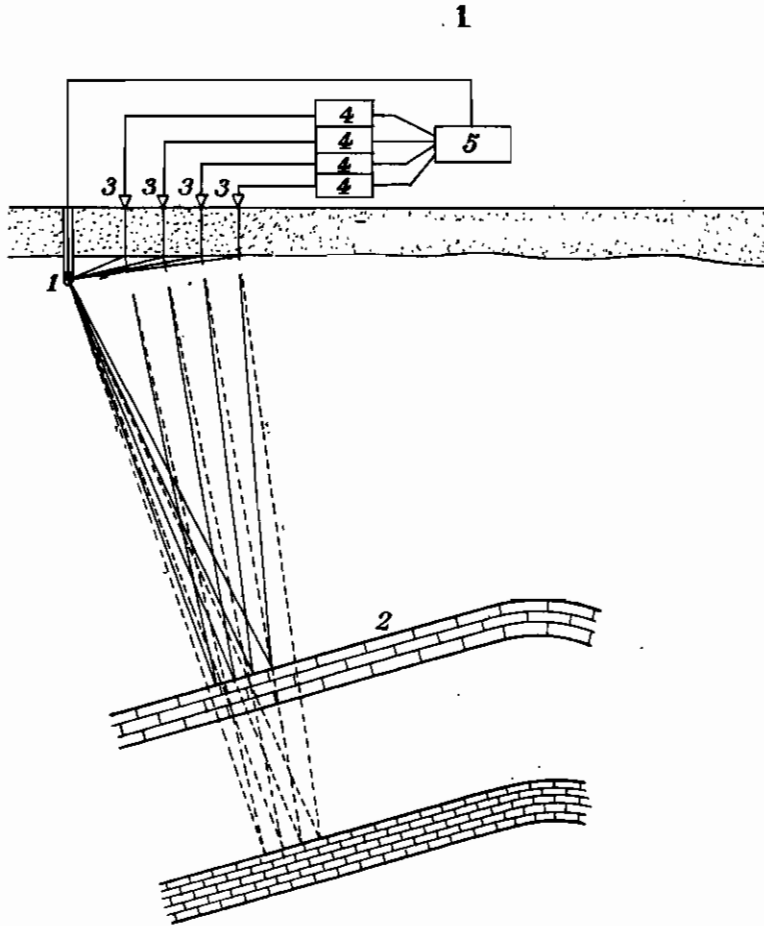. 1

2

INVENTOR
Raymond Maillet
by Benj. Chromy
L. attorney.
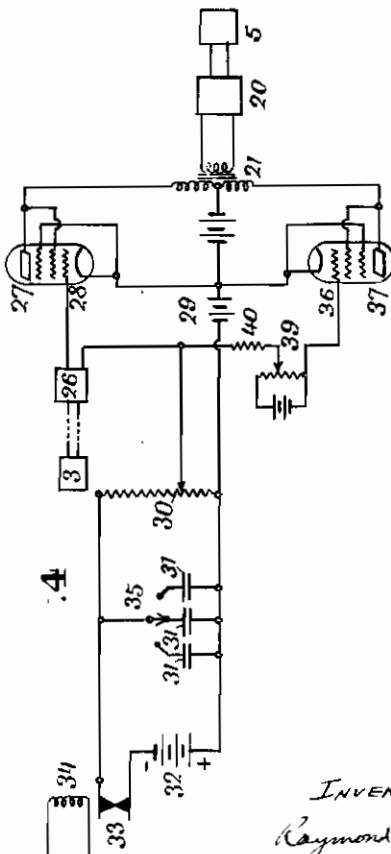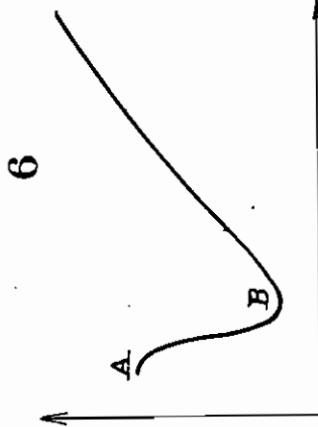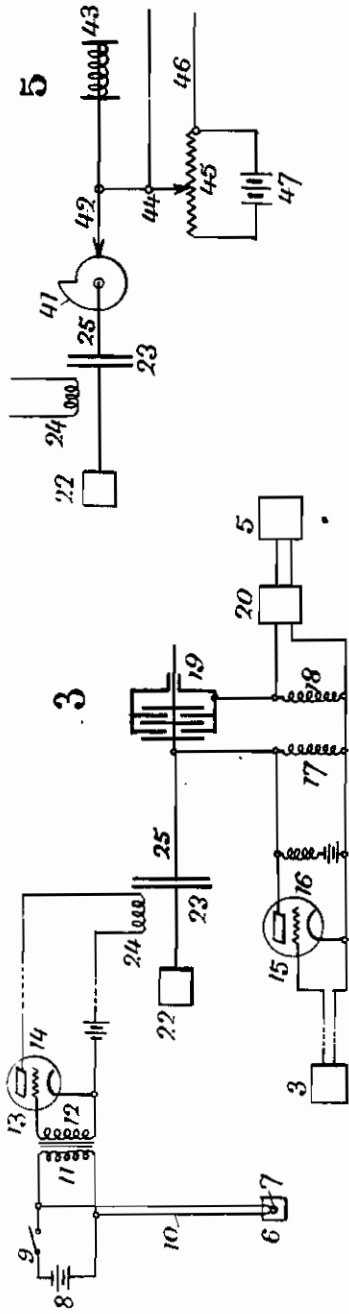
PUBLISHED

MAY 18, 1943.

BY A. P. C.

R. MAILLET
METHOD AND APPARATUS FOR SIESMIC
UNDERGROUND PROSPECTING
Filed Feb. 4, 1939

Serial No.
254,743

2 Sheets—Sheet 2

INVENTOR
Raymond Maillet
by Ben J. Lehromy
his attorney

ALIEN PROPERTY CUSTODIAN

METHOD AND APPARATUS FOR SEISMIC UNDERGROUND PROSPECTING

Raymond Maillet, Paris (16E), France; vested in
the Alien Property Custodian

It is known that in seismic underground prospecting methods, the time intervals elapsing between the emission of elastic waves from a given point and the return to the ground surface of said waves after reflection on the geological discontinuity surfaces of the underground are measured and observed by means of a plurality of seismographs suitably distributed over the surface of the ground or near said surface. From the various time intervals corresponding to the respective seismographs, it is possible to deduce the speeds of propagation, if the latter have not been determined in advance by direct measurements made in big bore-holes, and the depths of the various reflecting horizons, as well as their dips, in magnitude and azimuth. It is thus possible to obtain very accurate and very complete information concerning the tectonic structure of the underground.

Thus, seismic underground prospecting is very similar to echo methods as used in hydrography. As a matter of fact, this remark was made by Harvey C. Hayes, in a paper read on March 21, 1923 and published in the Journal of Franklin Institute (March 1924, pages 323 to 354). In particular, he made the following statement:

"The echo method of determining depths is not confined to determining submarine depths. It should serve equally well for determining the depths below the earth's surface of abrupt changes or discontinuities in the earth's crust such as are offered by coal and oil deposits or subterranean caverns. These surfaces of discontinuity will reflect to the surface a part of any sound disturbance that may be transmitted to them.

The train of sound or elastic waves is produced in any suitable manner, but most often by detonation of a charge of explosives, with sufficient stemming, placed for instance at the bottom of a small bore hole of a depth of some yards or some tenths of yards and filled with water. Or again this charge is placed on the bottom of a river, a lake, or the sea, or is buried in a furrow made in the ground with a linear density of charging sufficiently low to produce a camouflet effect. The seismographs, suitably distributed on the ground surface, but most generally buried at a small depth so as to protect them against the action of wind and, as far as possible, aerial sounds, collect the elastic energy fed by the various waves thus emitted, and transform it into electrical energy. The electromotive force supplied by each seismograph depends upon the displacement, or the speed, or again the acceleration of the ground, or upon one or several derivatives of this accelera-

tion, at the point where the seismograph is located, or upon a combination of these factors. After having been suitably amplified and filtered, the tensions supplied by the respective seismographs are transmitted to a multiple oscillograph which records them on a band of paper, or a photographic film, or otherwise, together with a signal indicating the time at which the waves were emitted, and the marks of an accurate time counter, for instance an electrically operated tuning fork. The oscillograms obtained are studied with a view to determining, among all the information supplied by the seismographs, that which corresponds to waves returned from the subterranean space after reflection on a geological contact, and to determining their time of propagation.

Theory and experience have taught that the propagation of the waves from the point of explosion is a highly complex phenomenon. On the one hand there are condensation waves, on the other hand distortion waves, both of these kinds propagating in all directions, and finally, close to the surface, bi-dimensional waves, especially the so-called Rayleigh and Love waves. These surface waves are the slowest; they have a considerable amplitude and this amplitude decreases rather slowly according to the distance of propagation, due to the fact that these waves are propagated only into two directions. They have a rather clear pseudo-periodic character and their frequency spectrum is essentially constituted by very low frequencies, say from 5 to 15 Hertz, by way of indication.

On the oscillographic records, it is of interest to eliminate the movements of the ground that are due to the waves of all kinds which have travelled close to ground or at a relatively low depth, and more especially the waves of the third kind, because these particular waves cannot give any interesting information concerning the geological and tectonic structure of the deep strata, but, on the contrary, risk over-charging the receiving apparatus, and anyway complicating the curves that are obtained, so that the identification of the reflected waves is made more difficult or even impossible.

These last mentioned waves, and especially the longitudinal reflected waves, have a highly complicated frequency spectrum, but the components that predominate therein are not so grave as those of the surface waves. By way of indication, the frequencies that predominate in reflected waves generally correspond to a range from 25 to 100 Hertz.

On the other hand, experience has taught that the discontinuity surfaces called "mirrors" give reflected waves such that, on the one hand the amplitude is lower, other things being equal, and, on the other hand, the frequency spectrum is poorer in sharp components, and therefore relatively rich in grave components, the lower the depth of these mirrors. The loss of amplitude is explained, at least partly, by the normal decreasing of this amplitude as a function of distance over which the wave has travelled and also by the energy losses due to the waves reflected by the successive geological contacts. The relative absorption of the sharp components in comparison with the grave components can reasonably be attributed to absorption and diffraction phenomena. For instance, some little coherent formations, such as sand, may be but imperfectly transparent. This phenomenon would be analogous to the gradual reddening of white light by fog.

Whatever be the causes, the first of the two above mentioned phenomena imposes the following conditions:

For given positions of the point from which the waves are emitted and of the seismographs, several successive experiments are necessary, with more and more intensive emissions, that is to say, as a rule with greater and greater charges of explosive. Low intensity emissions will permit of correctly recording the waves reflected from the shallowest mirrors. With the high intensity emissions, the over-loading of the apparatus and the distortion it produces, the intricate superposition of the various oscillographic tracings or the fact that they frequently run out from the field if the recording is effected by deviation, the reduction of the sensitized emulsion over its whole thickness if the recording is made with the variable density method, will not permit of observing the shallowest mirrors but, on the contrary, the deepest mirrors will supply reflected waves sufficiently intensive to be easy to discern on the oscillograms and to mark with accuracy.

But the fact of making several successive experiments at a given station involves a loss of time and money which should be avoided. It is possible to make a single experiment, with a sufficiently intensive emission of elastic waves for ensuring a suitable recording of deep reflections, provided that the sensitiveness of the receiving apparatus varies, according to a given law, as a function of the time having elapsed from the emission, and in such manner that the apparatus is never overloaded but that the gradual increase of sensitiveness as a function of time compensates the gradual decrease of amplitude of the successive reflected waves, in order to maintain a good readibility as the recording takes place.

As a matter of fact, it is still necessary, as a rule, to effect, in addition to the chief experiment above described, a recording with uniform and maximum sensitiveness corresponding to a low intensity emission, in order to determine, for each of the seismographs, the time at which the front of the fastest superficial wave reaches it. This time intervenes in the calculation of the corrections to be applied for taking into account the presence, under the ground surface of strata more or less decomposed by atmospheric and biologic influences and in which the conditions of propagation are abnormal.

The problem of automatically controlling the sensitiveness is similar to those existing is audible or ultra-audible sounding for the determination of submarine depths.

In this field of application, this problem was solved by automatically varying, as a function of time, the sensitiveness of the thermionic valve amplifiers interposed between the wave receiver (microphone) and the recorder. This automatic variation of sensitiveness is for instance obtained by varying, as a function of time and for one or several of the tubes of the amplifier, the polarization of their control grids.

On the other hand, the fact that, in the frequency spectrum of the reflected waves, the predominating components are less grave than is the frequency spectrum of the superficial waves has been used for a long time for eliminating or reducing the disturbing action of these superficial waves. The amplifiers have been rendered selective, and even have been combined with complete filters, the cutting off frequency being chosen low enough for allowing the gravest reflected waves to pass without too great an alteration, and high enough for intercepting the superficial waves as far as possible.

The object of the present invention is to take advantage of the property of the reflected waves of being relatively the richer in low frequencies as they come from the deepest mirrors.

This result is obtained, according to the present invention, by varying the frequency curve of the amplifiers as a function of the time having elapsed since the time of emission, in such manner as to permit the passage of components which are the graver the more considerable the time thus elapsed.

With this system, at the beginning of the experiment, the cutting off frequency or the passing band can be chosen relatively high for ensuring a good elimination of the superficial waves. This cutting off frequency or this passing band is then automatically varied and generally lowered gradually along the frequency scale, so as to permit a good recording of the waves which have been reflected from the deep mirrors, the superficial waves having then disappeared or, at least, having but reduced amplitudes which permit this lowering.

According to another feature of the invention I combine this characteristic with the automatic variation of sensitiveness as a function of time.

Another object of the present invention is to provide a device for obtaining these results.

Other features of the present invention will result from the following detailed description of some specific embodiments thereof.

Preferred embodiments of the present invention will be hereinafter described, with reference to the accompanying drawings, given merely by way of example, and in which:

Fig. 1 is a diagrammatic explanatory view illustrating the arrangement of the apparatus and the travel of the waves in the ground;

Fig. 2 is a diagram showing, by way of example, a recorded curve system;

Fig. 3 is a general view of a system according to my invention, including one of the seismographs, its amplifier, and a recording element, with means for automatically varying selectivity;

Fig. 4 shows another embodiment of the amplifier, ensuring automatic variation, as a function of time, both of selectivity and sensitiveness;

Fig. 5 is a partial view showing another embodiment of the invention;

Fig. 6 is a diagram showing, by way of example,

a sensitiveness curve corresponding to the arrangement of Fig. 5;

On all the figures, the same reference characters designate the same parts.

Fig. 1 shows a diagrammatic section of the ground. The waves are emitted from center I, the initial shock being generally produced by a charge of dynamite the importance of which depends upon the dimensions of the field which is to be studied, the charge being more considerable the deeper the mirrors to be detected.

I have shown the path of travel of the superficial rays, as well as that of the rays reflected from a deep mirror 2. These waves are received at suitably chosen points by means of suitable seismographs 3, connected through electric lines with a recording center provided with amplifiers 4 and a multiple recorder 5.

The recording of the various curves is generally effected on the same band in such manner as to obtain, for instance, the curves shown by Fig. 2.

In order to obtain the automatic variation of selectivity as a function of time, a method consists in disposing, at the input end of amplifiers 4, or between two stages of said amplifiers, a frequency filter of the high-pass kind, that is to say a filter which permits the passage of frequencies higher than a predetermined value and constituted, for instance, by a cell including two reactance coils in shunt with the line and a condenser in series therewith.

It is known that the cutting off frequency of a filter of this kind depends upon the value of the capacity of this condenser.

By varying this capacity, I obtain therefore the desired variation of the selectivity.

Fig. 3 diagrammatically shows a device for obtaining the automatic variation of the selectivity.

In this system, 0 is the charge of explosive located at the point of emission I of Fig. 1, and the ignition of which is produced by an electric detonator 7 operated by battery 0 through switch 9 and wires I0.

Battery 0 feeds in parallel the primary II of a transformer the secondary I2 of which is connected to the grid I3 of a vacuum tube I4.

The plate circuit of this tube is connected to the coil 24 of an electro-magnetic clutch located at the recording station and which is hereinafter described.

Reference numeral 3 diagrammatically shows a seismograph acting through a suitable line on the grid I5 of a vacuum tube I6 also located at the recording station.

In the plate circuit of this tube is inserted the filter above mentioned, this filter consisting of two reactance coils I7—I8 (generally with iron cores) mounted in shunt with respect to the line and the ends of which, opposed at their common point, are connected respectively to the two armatures of a variable condenser I9. The output of this filter feeds current to the other stages, diagrammatically shown at 20, of the amplifier, which controls one of the oscillographs of recorder 5.

Reference numeral 22 designates an electric motor which is started a short time before the charge of explosive is ignited. This motor drives, by means of an electro-magnetic clutch diagrammatically shown by the two plates 23, the rotor keyed on the spindle 25 of the variable condenser I9. This electromagnetic clutch is itself actuated by coil 24 which is inserted in the plate circuit of tube I4.

This apparatus works in the following manner:

Electric motor 22 turning at its normal speed, switch 0 is operated. During the short period of time (some thousandths of a second) necessary for bringing the filament of detonator 7 to incandescence, the source of current 0 is practically short-circuited and, consequently, the intensity in the primary II of the transformer is negligible.

The short-circuit approximately produced in the detonator is eliminated at the time of the explosion. This produces a substantial output or flow of current through primary II, and therefore an induced electromotive force at the terminals of secondary I2. The connections of the transformer are designed in such manner that this electro-motive force increases the potential of grid I3, whereby the plate current of tube I4 increases substantially at the time of the explosion. As a consequence, clutch 23 is let in and the rotor of condenser I9 is started rotating.

The outline of the blades of this condenser is chosen in such manner as to obtain the desired law of variation.

The impulses received by seismograph 3 are amplified by tube I6, and only the frequencies lower than the cutting off frequency are transmitted to the next stages 20 of the amplifier and to recorder 5.

This arrangement permits of obtaining the desired result, to wit an automatic variation of the cutting off frequency as a function of time.

It is clear, that the high-pass filter I7—I8—I9 might be completed by a low-pass filter including variable condensers also keyed on axis 25 which is driven through clutch 23. In this way, the last stages 20 of the amplifier would receive only frequencies ranging within two given limits variable as a function of time. The ensemble of the two filters (the high-pass filter and the low-pass filter) might be replaced by a band filter. On the other hand, it is clear that filter I7—I8—I9 might be constituted in any other way, the same as the control of clutch 23 might be made differently.

Fig. 4 shows another embodiment of the amplifier in which I obtain both the automatic variation of selectivity and that of sensitiveness.

The automatic variation of sensitiveness is obtained in this case by varying the polarization of the grids of one of the stages of the amplifier.

This stage is constituted by a tube 27, itself fed with current through a pre-amplifier 26, controlled by seismograph 3.

The polarization of the control grid 28 of tube 27 includes a constant portion supplied by battery 29 and a variable quantity which is given by the voltage drop across resistance 30.

This resistance receives the discharge current of a condenser 31 which is charged by battery 32 across the contacts 33 of a relay, normally closed, the coil 34 of which receives the plate current of a tube I4, mounted exactly in the same manner as in the example shown by Fig. 3. Therefore, this coil 34 replaces the coil 24 of this Fig. 3.

It will be readily understood that, at the time of the explosion, coil 34 attracts its armature which opens contacts 33. Therefore, condenser 31 is gradually discharged through resistance 30. It follows that the polarization is maximum at the time of the explosion and decreases in a continuous manner as a function of time. The constants of the law according to which it de-

creases are adjustable owing to the choice of condensers **31**, through switch **35** and of the adjustable point of contact on resistance **30**. Therefore, in this way, I fix on the one hand the time of relaxation of the variable polarization and, on the other hand, the initial value thereof. It goes without saying that these two adjustments might be obtained otherwise.

The plate current of tube **27** is in turn transmitted, through a transformer **21**, to the other stages **20** of the amplifier which feed current to recorder **5**.

It will be readily understood that, as a consequence of the variation of the polarization, the plate current of tube **27** increases in a continuous manner as a function of time. It therefore follows that a parasitic signal is produced which would be transmitted to the next stages of the amplifier. In order to eliminate it, I mount in opposition on tube **27**, according to a well known arrangement, an identical tube **37** the control grid of which, **36**, receives the variable polarization from resistance **30**, but of course does not receive the signal from **26**. Therefore, transformer **21** is of the push-pull type as shown by the drawing.

Furthermore, on the control grid **36** there is mounted a potentiometer **39**, which permits of adjusting the polarization of **36**, in such manner as exactly to balance the increases of the anode currents of tubes **27** and **37**, when there are variations of polarization at the terminals of resistance **30**. Furthermore, I insert, if need be, a resistance **40** in the grid circuit **38** to balance the impedance introduced in the circuit of grid **28** of tube **27** through the pre-amplifier **26**.

It will be noted that tube **27** is constituted by a pentode the suppressor (the grid closer to the anode) of which is connected to the cathode, the screen grid being directly connected to the plate.

On the other hand, in this tube, it is very advantageous to arrange this control grid in such manner that the spires thereof are at intervals which increase gradually from one end of this electrode to the other end thereof. In other words, it is advantageous to employ, as tubes **27** and **37**, so called "selectode" or "supercontrol" tubes.

This arrangement permits of obtaining the automatic variation of selectivity as a function of time. It is known that the variation of the plate current of a thermionic valve as a function of the frequency is the greater (for a predetermined variation of the control grid tension) the lower the internal resistance of the tube, the influence upon the plate current of the charge impedance (constituted in this case by transformer **21**) being the more considerable as the internal resistance is lower.

In order fully to explain this point, it should be remembered that, below the secondary resonance and dispersion frequencies, a transformer coupling, (such as that obtained with **21**) produces, in point of fact, the same effects, to within a constant factor (equal to the transformation ratio a), as a coupling obtained through a reactance coil L_1 constituted by the primary of this transformer. If R_1 designates the total resistance of the primary circuit, essentially constituted, in this case, by the internal resistance of tube **27**, the gain is given by the following formula:

$$\frac{Ka}{\sqrt{1+\left(\frac{R_1}{L_1\omega}\right)^2}}$$

in which K designates the factor of amplification of tube **27** and ω the circular frequency of the signal.

For a given value of said frequency, the gain increases, other things being equal, when resistance R_1 decreases. Therefore the range of the frequencies that are transmitted will gradually extend toward lower and lower frequencies, as the time elapses from the explosion, if the internal resistance of the tube gradually decreases. Now, the gradual disappearance of the grid polarization available at the terminals of resistance **30** will gradually open a passage for the electrons through the zones of tube **27** where the pitch of the control grid **28** becomes smaller and smaller and thus gradually lower the internal resistance of tube **27**.

It should be noted that the problem in this case is exactly the inverse of the conditions existing in radio-telephony for the amplification of high and mean frequencies with an automatic control of the gain. In this case, it is endeavoured to make tubes, the internal resistance of which is, under all circumstances, very high as compared with the charge impedance. This is the reason why selectodes are, in a general manner, tubes having a screen grid (tetrodes, pentodes, etc.) and why it is difficult to find, on the market, selectode triodes, that is to say tubes of this kind having a grid pitch variable along said electrode. But it is clear that the present invention might be carried out by employing, as tubes **27** and **37**, such selectode triodes, if they were constructed. As a matter of fact this is not necessary because I have found by experience that, by taking pentode tubes of the E. F. 5 type or of the American 956 pentode gland, and by connecting, in these tubes, the screen grid to the plate, I obtained the equivalent of a low internal resistance triode. Furthermore, the value of this internal resistance varies gradually and within wide limits in accordance with the negative polarization of the control grid. Therefore, tube **27** (and also, of course, tube **37**) can be merely constituted by 956 type, or E. F. 5 type tubes, or the like, in which the screen grid is directly connected to the plate.

It will be noted that, in the arrangement illustrated by Fig. 4, the law of variation of the polarization as a function of time is necessarily an exponential law (discharge of a condenser across a resistance). If it is desired to obtain another given law, the polarization variation is controlled through an arrangement of the kind of that shown by Fig. 5. This arrangement includes the motor **22** of the embodiment of Fig. 3, with its clutch **23** controlled by coil **24** fed with current through tube **14**.

Shaft **25** carries in this case a cam **41** (shown in front view on the drawing) cooperating with a finger **42** applied against the periphery of said cam by a spring **43**. This finger controls the sliding contact **44** of a variable resistor **45**, acting as a potentiometer owing to the provision of a battery **47**. With such an arrangement, the potential difference between the end **46** of the resistance and finger **44** varies automatically as a function of the time. This voltage replaces that existing across the terminals of resistance **30** in Fig. 4.

By suitably choosing the outline of cam **41**, it is easy to obtain any desired law of variation, without any limitation.

In particular, this variation permits of obtaining a variation of the sensitiveness as a function

of time such that sensitiveness is higher at the beginning, then drops rapidly to a relatively low value, and subsequently increases in a continuous manner as a function of time. The curve of sensitiveness corresponding to this is that of Fig. 6. This arrangement permits of correctly recording the front of the fastest superficial waves, the times of arrival of which correspond to portion A of the curve, of eliminating the high amplitude oscillations of the superficial waves which come next, and in particular the Rayleigh or Love waves which arrive during the time period corresponding to portion B of the curve, and finally of correctly recording the reflected rays coming from deeper and deeper mirrors.

Of course, the above mentioned arrangements are not the only possible embodiments of the invention within the scope of the principle thereof.

In particular, in the arrangement of Fig. 4, I might arrange tubes 27 and 37 in such manner as to constitute a true push-pull system, the signal coming from pre-amplifier 26 being applied, in phase opposition, to grids 28 and 36, according to a well known mounting, the variable polarization voltage being of course the same in magnitude and direction for each of the grids.

It is clear that, in this case, the increases of current, in the anode circuits, resulting from variations of polarization still eliminate each other.

RAYMOND MAILLET.