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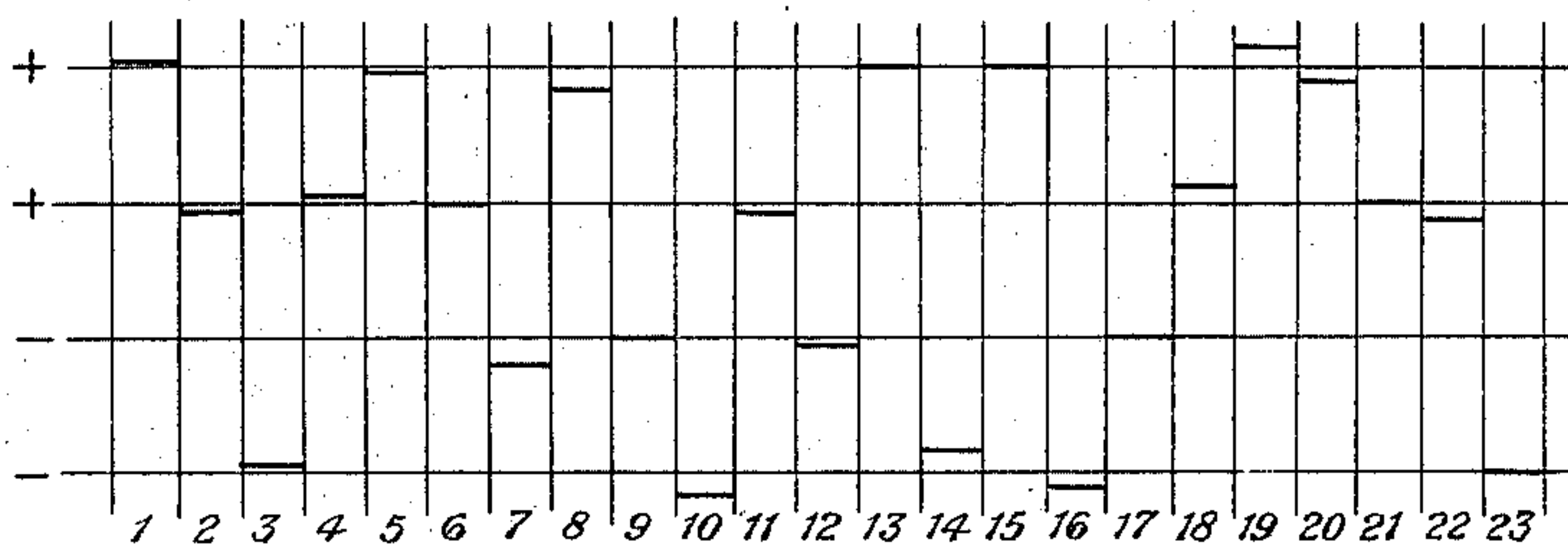
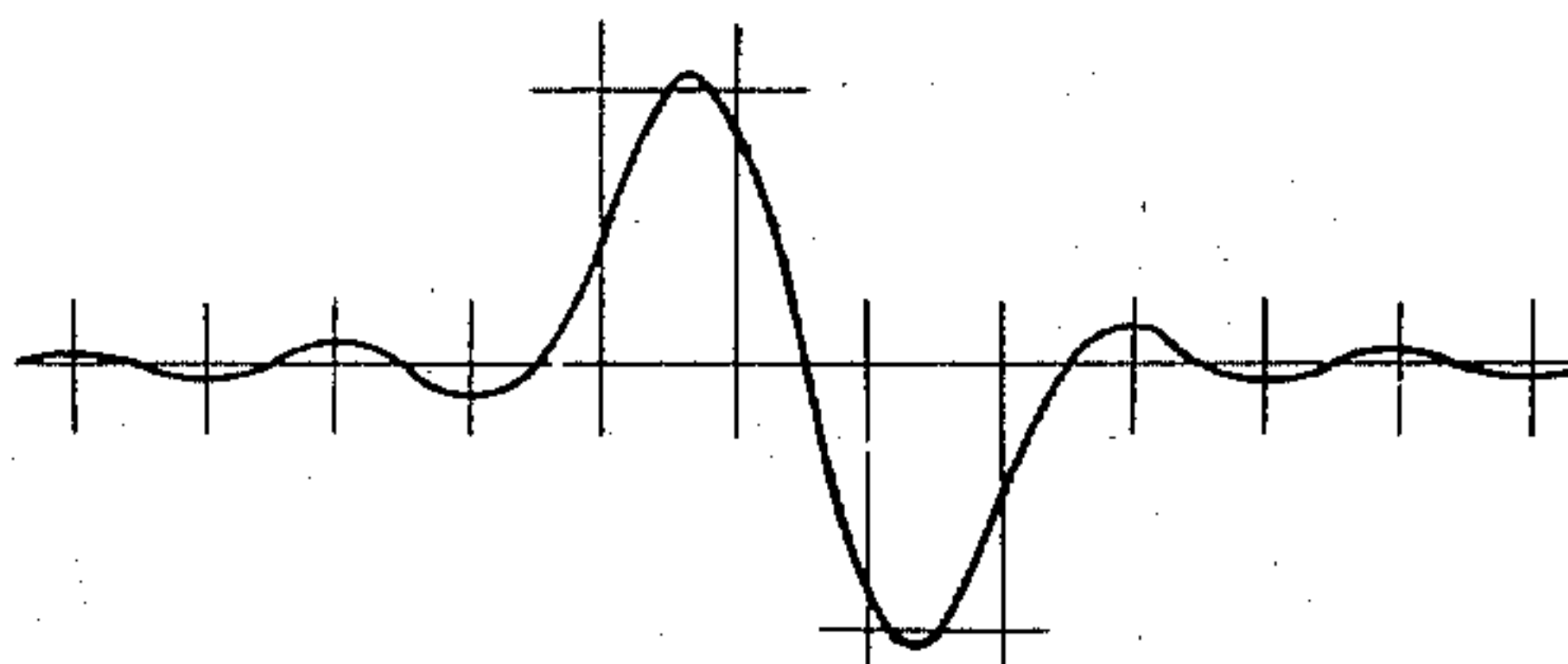
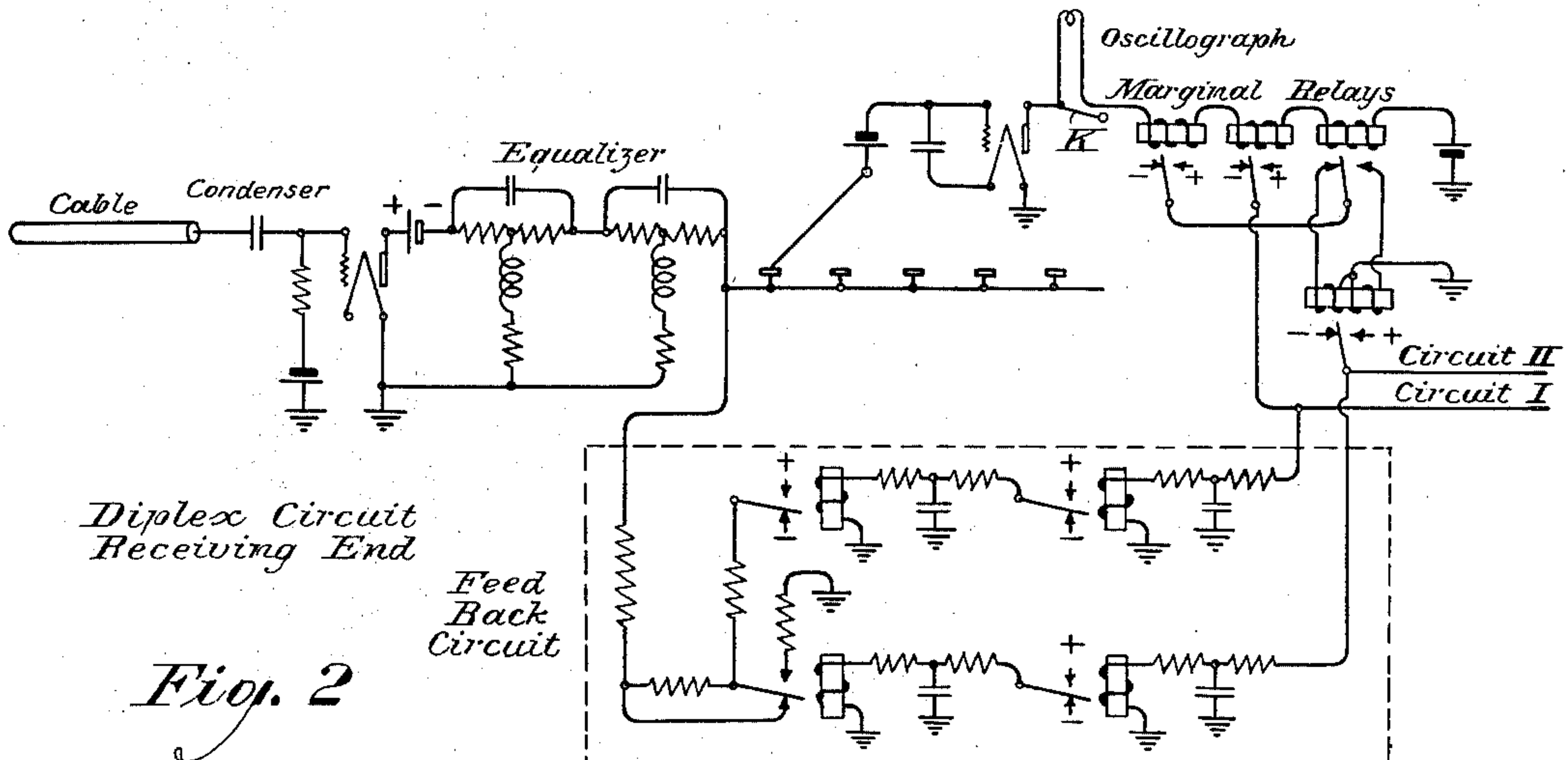
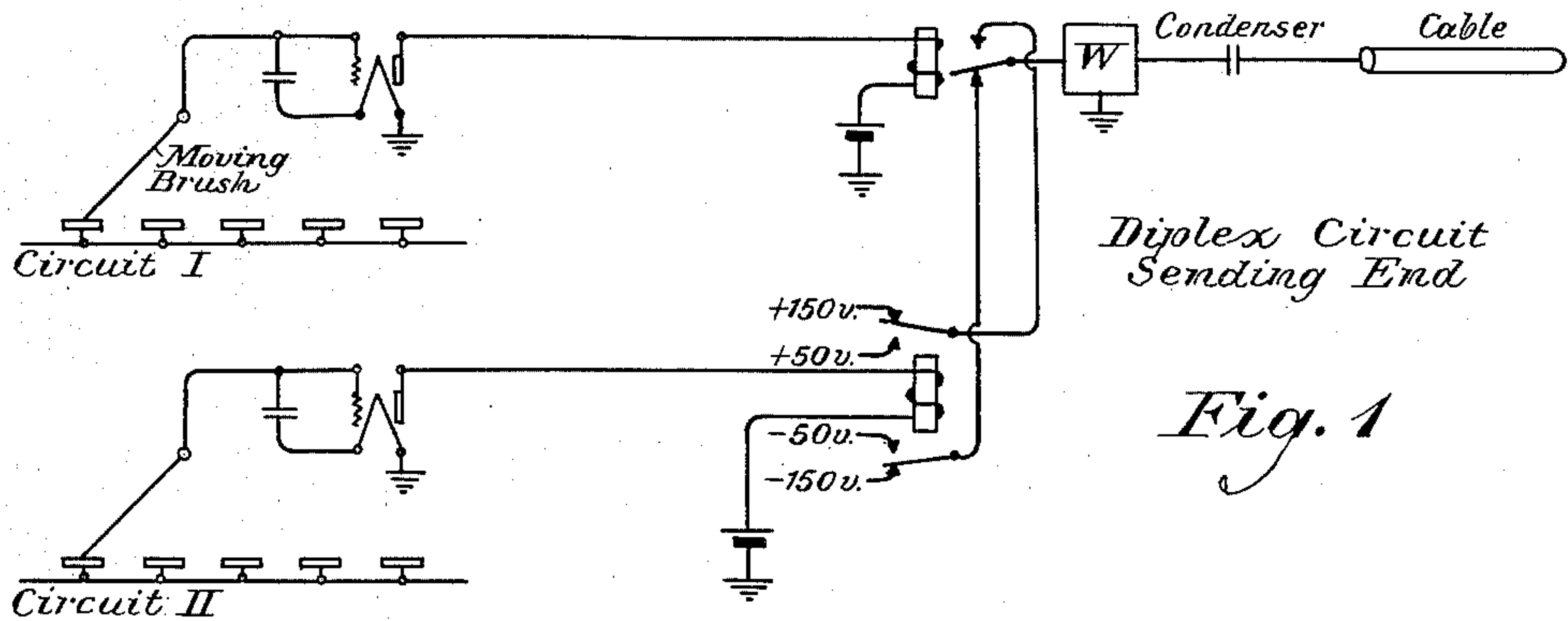
H. NYQUIST

1,922,139

TELEGRAPH SYSTEM FOR SUBMARINE CABLES

Filed Sept. 7, 1932

2 Sheets-Sheet 1



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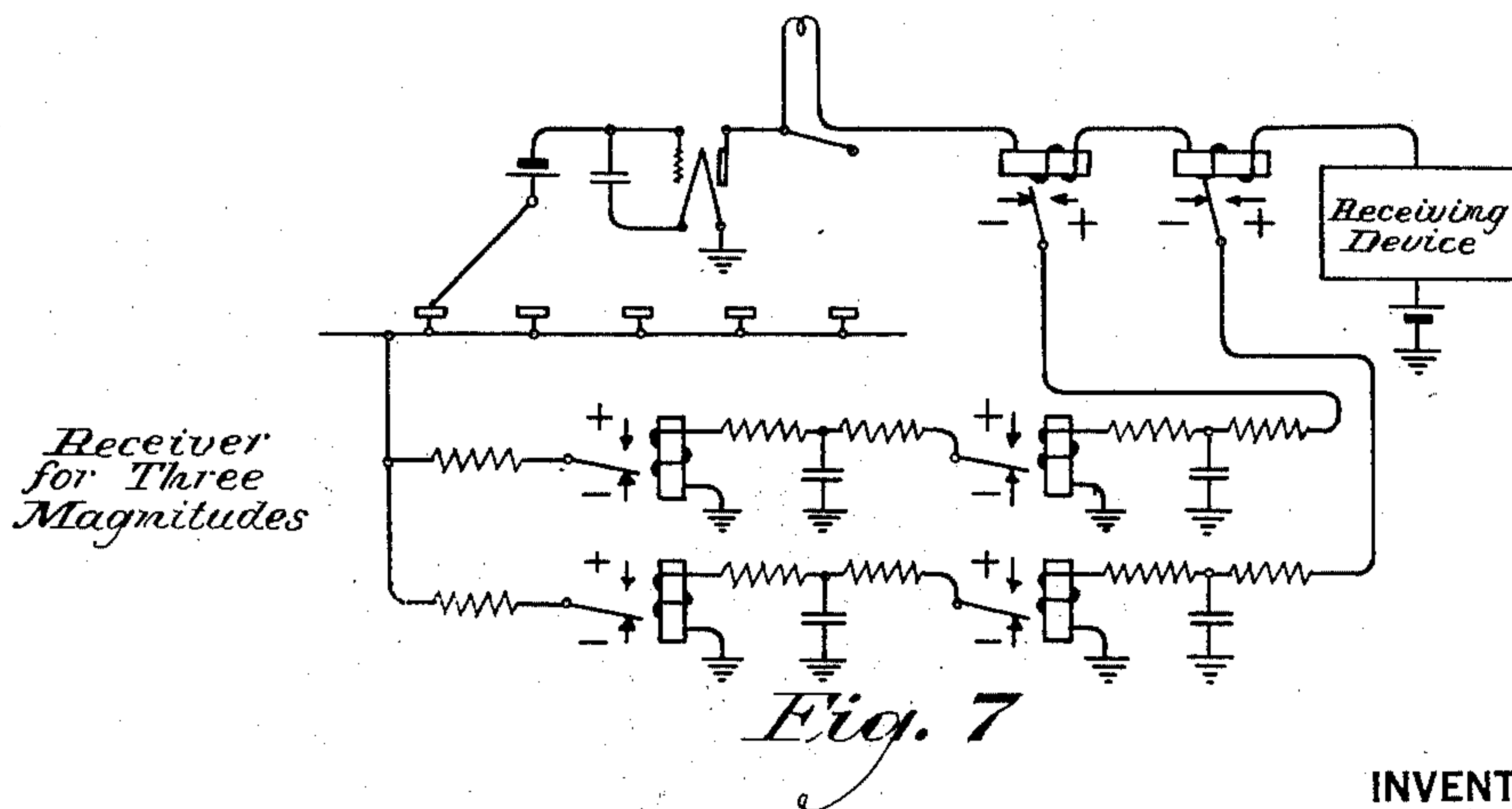
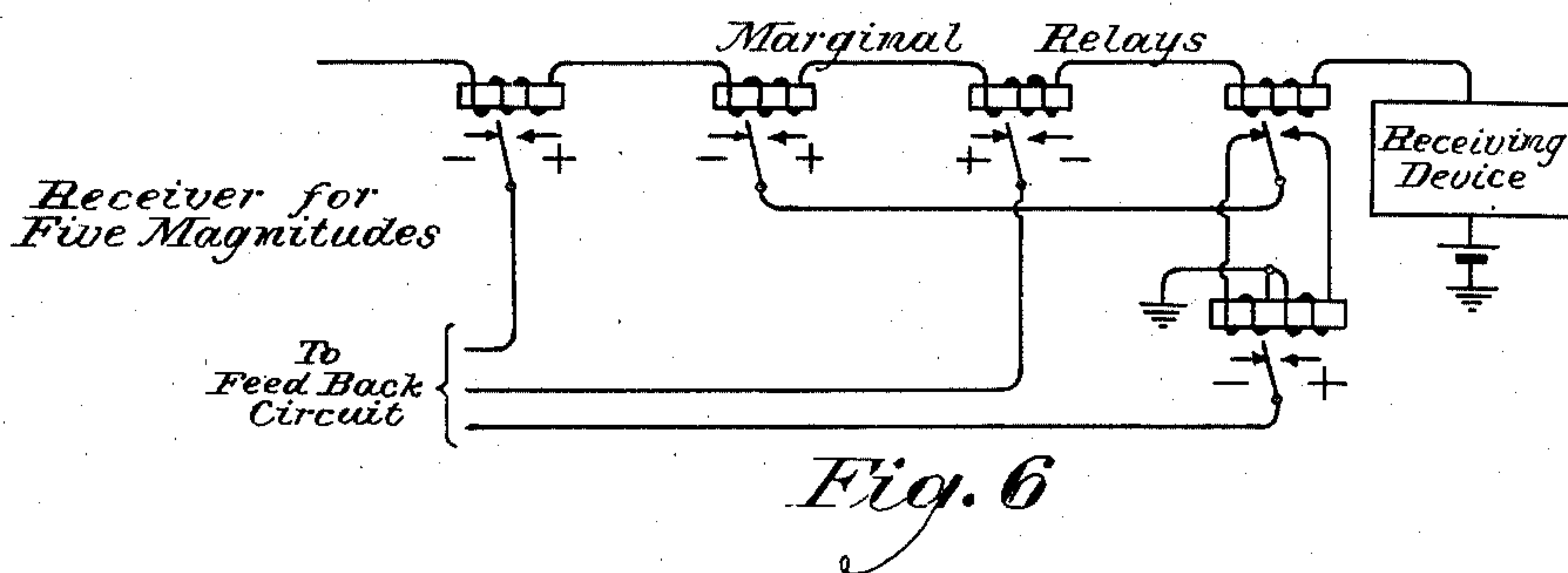
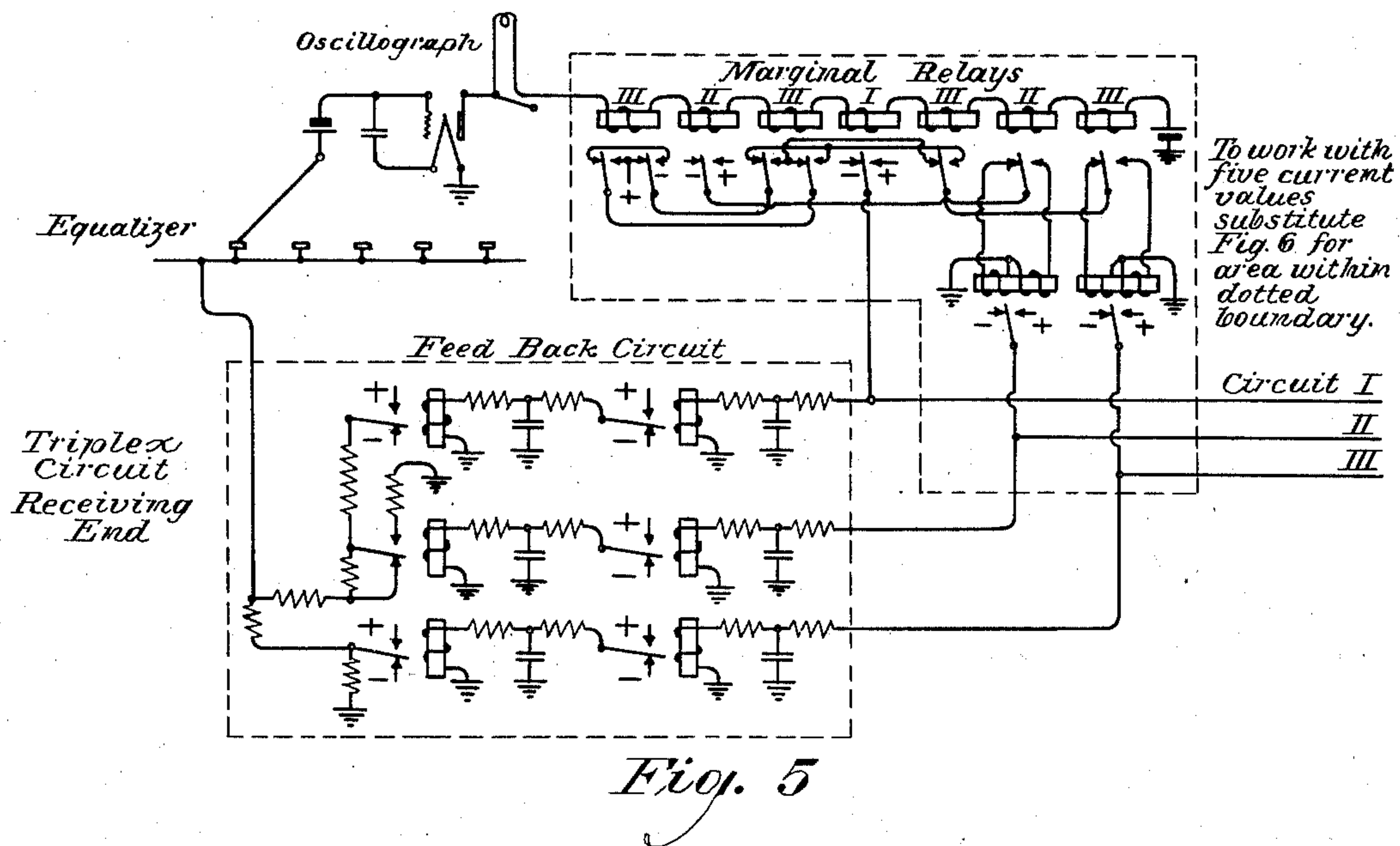
H. NYQUIST

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TELEGRAPH SYSTEM FOR SUBMARINE CABLES

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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

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TELEGRAPH SYSTEM FOR SUBMARINE
CABLES

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a Corporation of New York

Application September 7, 1932
Serial No. 632,011

17 Claims. (Cl. 178—63)

This invention relates to telegraph systems for submarine cables and similar transmission lines. Its purpose is to increase the speed of transmission of signals through such signaling circuits and to increase the reliability of operation. Another purpose is to construct a signaling system which is as free as possible from the characteristic interference normally present in such systems. A further purpose is to obtain a form of received signaling unit which shall best lend itself to such ends. Still a further object is to design a cable or transmission line with associated apparatus which is best adapted for leading to the production of the preferred wave form at the receiving end. Still another purpose is to design terminal receiving apparatus which shall be operated effectively and accurately by the preferred wave form at the receiving end.

My system relates to a cable which is unable to transmit direct current or alternating current above a certain frequency s and in such a system, by my invention, it is possible to be as free from characteristic interference as one cares. For this reason, I can transmit as many different current values as desired and so increase the speed of signaling or increase the number of signaling channels.

In my system, if one sends as a signaling unit a square-top impulse covering one time unit of a duration related to the maximum transmission frequency for the cable, the current on the cable changes in form and at the receiver is spread over several time units in accordance with certain characteristics hereinafter set forth. In this train of impulses at the receiving end, the main signal is followed by a trailing signal of substantially the same magnitudes but of opposite sign. In my system I provide a feed-back arrangement at the receiver which generates a local impulse properly valued and properly timed to substantially neutralize the received trailing impulse. Also, on this cable, in case a train of impulses of frequency s is transmitted, the received current resulting therefrom approaches zero since the cable does not transmit the frequency s but, in spite of this, the feed-back arrangement acts to keep the receiving mechanism operating as long as no change occurs in the signals at the sending end.

These and other features of my invention will be pointed out and explained in connection with the following specification and accompanying drawings, in which Figure 1 shows the sending end of a duplex circuit and Fig. 2 shows a corresponding duplex receiving end. Fig. 3 shows the preferred wave form which I designed my cable

to produce. Fig. 4 is a portion of a record such as might be produced by the receiving apparatus of Fig. 2. Figs. 5, 6 and 7 relate to the receiving end of circuits using various numbers of current signaling magnitudes.

One characteristic of submarine cables is that their cost is so great that it is economically desirable to go to great lengths to obtain as high a speed as possible even when this means greatly complicating the terminal apparatus. Another characteristic of such cables is that they are subject to interferences of very low frequency which usually necessitates suppressing the transmission of direct current. Also such cables have a limiting frequency above which it is not possible to transmit messages which will be effective on the receiving apparatus. An outstanding problem then in submarine cable signaling is to transmit up to the maximum frequency transmitted by the cable with the handicap of having no transmission of direct current. This specification gives an analysis of the requirements for and specifies a system which will transmit without distortion under these conditions.

In the April 1928 "Transactions of the American Institute of Electrical Engineers", page 617, I published an article entitled "Certain Topics in Telegraph Transmission Theory" to which reference will be made from time to time in this specification. In that article, it was shown that the intelligence conveyed by a telegraph signal is fully contained in a band of frequencies extending from zero to a frequency s equal to the speed of signaling in dots per second, where the dot may be considered as made up of two time units, one for the marking direction and one for the spacing duration. It was shown that this is true regardless of the number of current magnitudes used in the signaling. It was also shown that the omission of any continuous range, however narrow, from the range just specified may, with certain signals, lead to the reception of an incorrect signal. Finally, it was shown that, while a continuous range may not be omitted, individual frequencies may be omitted. In the latter case, the signal received must be supplemented by information derived from its previous history, as will be more apparent below.

I will, first, consider the specific problem of a telegraph circuit whose transmitted range does not extend beyond the frequency s and whose transmission is zero for direct current and for the frequency s . Let it be required to provide a telegraph system using four magnitudes or current values at the speed of s dots per second.

Further, let it be required that the characteristic or inter-symbol interference be kept very small. By the characteristic interference is meant that due to the accumulation at any instant at the receiving terminals of the trailings or distortion due to the signals which have arrived or are to arrive at the receiver terminals.

Let a, b, c, d be the four current values and consider the signals $aaa \dots, ababab \dots, acacac \dots$ etc. There is a total of sixteen such distinct signals which, as indicated may be continuous for a long time. These sixteen signals, while distinct, have this in common, that they are made up of no other frequency components than direct current, s cycles, $2s$ cycles, $3s$ cycles, etc. In other words, these signals contain no frequencies transmitted by the telegraph circuit. The ultimate received current is zero in all these cases, although the beginnings and endings will be indicated by transients, the nature of which will depend on the signal sent. In spite of this, the telegraph system should be constructed to continue to receive the correct signal even after substantially no current is being received.

While, as stated above, the ultimate current is the same in the case of these sixteen signals, they differ in the manner in which they approach that final value and the telegraph system must, accordingly, be such as to receive an impression of the right sort while the current dies out and to continue receiving in accordance with that impression as long as the current remains zero, that is until the transients due to the end of the train of signals arrive. To do this, the system must be capable of keeping itself going, that is, it must have a feed-back property.

Let us consider a signal element made up of successive impulses each of a duration equal to the marking or the spacing time for a dot, that is, of a duration $\frac{1}{2}s$. I may assume that the current in the middle of the first time unit is α , in the middle of the second β and so on and, after a small number of such time units the value becomes zero. Then the system can be made to receive properly provided the value at the middle of the first time unit is used for reception and provided that the values β etc. are made ineffectual by arranging matters so that the reception of α causes a neutralizing current $-\beta$ etc. to be fed back into the circuit at the proper instant.

I will assume, tentatively, that the received current, due to a unit impressed signal element in the first time unit, is α, β and γ in the middle of the first, second and third time units, respectively, and is zero in the middle of all other time units.

In order that this should be possible in a system transmitting no direct current, it is necessary that

$$\alpha + \beta + \gamma = 0.$$

Likewise the assumption that the system is to transmit no current of frequency s leads to the requirement

$$\alpha = \beta + \gamma = 0.$$

These two equations may be rewritten as

$$\begin{aligned} \beta &= 0 \\ \gamma &= -\alpha \end{aligned}$$

Consequently, a signal element of value $+1$ in the middle of the first time unit, -1 in the middle of the third and 0 in the middle of all the others should be considered. Such an element is indicated in Fig. 3 of the drawings. I have found that its properties are such as to make it a par-

ticularly useful and preferred form of wave. As will be pointed out later in my invention, I so design the transmission system that a single flat-topped impulse of a unit-timed duration will, as it proceeds through the cable and associated networks, gradually shape itself so that when it reaches the receiver terminals, it will have produced a wave-shape of the form of Fig. 3.

Now, if I send a succession of impulses each capable, when considered alone, of producing at the receiver a wave of the shape of Fig. 3, and these impulses follow each other in successive time units, I will receive a wave whose beginning and ending will be indicated by transients bearing some relation to the principal parts of the wave of Fig. 3, but between the beginning and ending transient conditions, the wave will have a steady-state value of zero. For example, if a second wave like Fig. 3 is superposed on that wave one time unit later, the second wave will attain its maximum positive value $+1$ just when the first wave is passing through zero in the middle of the second time interval, i. e., the time interval between the $+1$ and -1 values of the first wave. Hence the $+1$ values of both waves will follow each other and neither will be suppressed. If a third wave like Fig. 3 is received in a third time interval, it will attain its $+1$ value just as the first wave reaches its -1 value and at the time the second wave is passing through zero, midway between its $+1$ and -1 values. The $+1$ element of the third wave cancels the -1 element of the first wave and the resultant of all three waves during this third interval is zero, and likewise, the $+1$ element of a fourth wave will cancel the -1 element of the second wave while the first and third waves are passing through zero. Consequently, after the $+1$ impulses of the first and second waves are received, a zero steady-state condition continues as long as the train of impulses is sent, but this steady-state condition is followed by a transient built up from the superposition of the last two waves like Fig. 3 which correspond to the last two impulses.

The considerations from now on will be divided into two parts. The first will consist of specifying the transmission characteristics or signal-shaping devices, or both, which lead to a received wave having the properties indicated and the second part will consist in specifying a telegraph system capable of operating on such a received wave. The transmission characteristic of chief interest in this connection is one which we will call "transfer admittance" (Y) which is herewith defined as the ratio of the numerical value of the received wave to the sent wave, regardless of the nature of these values. That is $F_r = YF_s$, where F_r and F_s represent the received and the sent waves, respectively.

Instead of working out the transmission characteristics directly, they may be obtained indirectly by making use of the results of my article referred to above. It is shown in appendix II-A (Equations 8 and 10) that the shape factor

$$\begin{aligned} F_1(\omega) &= 2, & 0 < \omega < 2\pi s \\ F_1(\omega) &= 0, & 2\pi s < \omega \end{aligned} \quad (1)$$

corresponds to a wave such that the current is unity in the middle of the first time unit and zero in the middle of all the others. It follows that a wave whose received current is unity in the middle of the third time unit and zero in the middle of all the others is given by

$$\begin{aligned} F_3(\omega) &= 2 (\cos \omega/s - i \sin \omega/s), & 0 < \omega < 2\pi s \\ F_3(\omega) &= 0, & 2\pi s < \omega \end{aligned} \quad (2)$$

The required shape factor then for a wave such that the current is +1 in the middle of the first time unit and -1 in the middle of the third time unit and 0 in the middle of all other time units is obtained by subtracting (2) from (1). It is

$$F(\omega) = 2(1 - \cos \omega/s + i \sin \omega/s), \\ = i 4 (\sin \omega/2s) (\cos \omega/2s - i \sin \omega/2s), \\ F(\omega) = 0, \quad \begin{matrix} 0 \leq \omega \leq 2\pi s \\ 2\pi s < \omega \end{matrix} \quad (3)$$

If the sent signal element is a rectangular wave coincident with the time unit to which it appertains, I have, as shown in my article, for the shape factor at the sending end

$$F_s(\omega) = \frac{8 \sin(\omega/4s)}{\omega/s} \quad 0 \leq \omega < 2\pi s, \quad (4)$$

The required transfer admittance is

$$Y(\omega) = \frac{F(\omega)}{F_s(\omega)} = \frac{(i\omega/s) \sin(\omega/2s)}{2 \sin(\omega/4s)} = i\omega/s \cos \omega/4s, \quad (5) \\ Y(\omega) = 0, \quad \begin{matrix} \text{for } 0 \leq \omega \leq 2\pi s, \\ \text{for } 2\pi s < \omega \end{matrix}$$

In obtaining this last equation, the time factor has been omitted, since it refers to the delay due to transmission of the signal over the cable. Such omission of time factor is equivalent to shifting the time origin and this may be done arbitrarily to any desired extent. The cable, with which we are to operate, should thus have or be given a transfer admittance given by Equation 5. Certain latitude, however, is permissible for it is clear that before specifying Y the shape factor

$$i 4 \sin(\omega/2s)$$

may be supplemented by other shape factors such as shown in Fig. 2 at b and d in my article. This then leads to a choice of values for Y .

When the required transmission characteristic Y has been determined as above and when the transmission characteristic of the cable has been computed or measured, the specification of the equalizers or signal shaping networks to give an overall characteristic Y is straightforward. This invention does not concern itself with the computation of equalizers, partly because many forms of equalizers will be satisfactory and partly because the procedure of designing the equalizers varies in accordance with the given line characteristics. In general, the modifying of the cable to bring it to the characteristic Y can be accomplished by equalizers of the type now well known in connection with transmission circuits. But, in case it should be desired, these equalizers may be supplemented by shaping the sent signals. This may be done in accordance with appendix VII of my article referred to above or in accordance with my United States Patent No. 1,794,806 of March 12, 1929. The discussion in appendix VII becomes applicable in this case by putting $f_r(t) = +1$ for $h=1$, $f_r(t) = -1$ for $h=3$ and $f_r(t) = 0$ for all other values of h . The subsequent Equation 16 then finally becomes $b_n = \text{real part of}$

$$\frac{N/2-1}{N} \sum_{n=1}^{\infty} \frac{e^{i \frac{2\pi n}{N} (h-1+2s\gamma)} - e^{i \frac{2\pi n}{N} (h-3+2s\gamma)}}{\sin \frac{\pi n}{N} \sum_{q=-\infty}^{\infty} \frac{y(4\pi s(q+n/N))}{\gamma(q+n/N)} e^{-i(4s\gamma+1)q\pi}} \quad (6)$$

Fig. 1 shows the sending end of the transmission system in schematic form. The system is shown as a duplex type in which two systems of

two magnitudes each are combined to form a single system of four magnitudes. The two contributing circuits are of the synchronous printer type comprising a rotating brush passing over a number of segments circularly arranged, over which the signals to be impressed on the cable arrive. Care is taken that the two circuits work synchronously with each other. The four voltages impressed may be -150, -50, +50, +150 and all the relays in Fig. 1, as well as in the following figures, are shown in marking position. A condenser is added to block low frequency interference and, if desired, a wave shaping device W of the kind described in my United States patent referred to above may be introduced to supplement the action of the equalizers.

Fig. 2 shows the receiving end in schematic form, there being again a condenser for blocking low frequency interference. There is also shown a set of amplifiers and equalizers. After amplification and equalization, the signal is passed to a distributor which is run in accurate synchronism with the distributor at the sending end. The mechanism for maintaining the synchronism is not shown but will be taken up further below. The distributor is so arranged that only a small portion of the segments corresponding to the middle of the time unit is active. During this interval, the cable is connected to the grid of a vacuum tube. Until the next segment is reached, this grid holds its potential and a substantially constant current flows in the plate circuit of the vacuum tube. Thus, the response of the receiver relays is independent of the intensity of the wave at other times than the middle of each time unit. It is necessary, therefore, only to see that the received wave has the correct magnitude, as it reaches the receiver, in the middle of the time units only. The current from the vacuum tube causes a set of marginal relays to operate and these, in turn, cause the circuit to be separated into the two component parts, circuit I and circuit II, all in a manner well known in the art. In addition to receiving the signal from the line, the distributor also receives the feed-back wave which has been mentioned above and which will now be discussed more fully.

When the first two signal elements of a message are being received, there is no difficulty apparent for the reason that the first signal element has zero value at the middle of the second time element, as shown in Fig. 3 and therefore produces no interference. When, however, the third signal element is being received, complications arise from the fact that the first signal element superposes on the third signal element a signal which is equal to the first and opposite in sign, as again seen from Fig. 3. To eliminate this interference, the feed-back circuit of Fig. 2 is arranged to impress a current of the same value as that received and so adjusted as to time delay, etc., that it arrives at the input of the receiver two time units after the impulse which initiated it. This time delay is controlled by the time constants of the resistance and condenser elements shown in the feed-back circuit and by the time constant of the mechanically moving relay tongue. In the figure, there are shown two relays in tandem for the purpose of introducing the approximately correct delay and a precise adjustment of the delay may be obtained by varying the electrical or the mechanical stiffness and inertia of the various elements. From this, it will be seen that if there is received in the n th time unit a wave of the form of Fig. 3 which has zero value

at the middle of all time units except the first and the third, then, in that n th time unit the received current is 1 and there will be an interfering current of -1 from the line in the $(n+2)$ th time unit and a feed-back current of $+1$ in the $(n+2)$ th time unit. Thus the characteristic interference is eliminated and the receiver is ready for the next signal element. A little consideration will show that if a series of dots are sent for an indefinite length of time, the system, by virtue of the feed-back arrangement, will continue to record the receipt of dots so long as the signaling conditions at the transmitting end are not changed.

It has been assumed that the receiving distributor runs in close synchronism with the sending distributor. Approximate synchronism may be maintained by means of any suitable device such as a crystal oscillator. This, however, is insufficient for my purposes. To obtain closer synchronism, an oscillograph of the type that develops and fixes the film may be employed. Thus, by operating the switch K in Fig. 2, a record may be obtained of the kind well known in the art, such as that shown in Fig. 4. The record has ruled on it four parallel lines which correspond to the four currents which should be received under conditions of no interference. Due to various sources of interference, the actually received current does not coincide with the expected value. One source of interference is the lack of synchronism. By reference to Fig. 3, it will be seen that the curve of the received current is very steep in the middle of the second time unit. This has a marked value in this connection for, if the signal is lagging behind the receiving mechanism, there will be a component of interference present whose sign is the same as the received current on the preceding time unit and this component will be the larger if the received current is very steep at the point indicated. On the other hand, it will be seen that if the receiving mechanism is lagging behind the incoming signal, there will be a similar component of interference of opposite sign to the received current of the preceding time unit. Applying this to Fig. 4, I see that the current received in 1 is positive and the interference received in 2 is negative. This is evidence that the receiving device is lagging and should be advanced. The current received in 2 is positive and the interference in 3 is positive. This is evidence that the receiving device should be retarded. Similarly, 3 and 4 give evidence that it should be advanced. Denoting evidence that it should be advanced by a and evidence that it should be retarded by r , I have the following evidence from units 1 to 11, inclusive, $a, r, a, a, o, a, r, o, r, r$. On the whole, then, there is no evidence that there is any adjustment required. The interference is largely due to other sources than lack of synchronism.

If an adjustment is indicated, this should be an adjustment of brush position rather than of frequency. Adjustments of frequency should be made only when it is certain that there is a steady drift. Moreover, frequency adjustments should be limited to one station, say the west one.

It will be obvious that the oscillographic record of Fig. 4 can be used for establishing the need for adjustments other than those of synchronism. For instance, if the received current tends to be numerically too large, the gain of the receiving device should be decreased. If it tends to be too

large algebraically, the space current should be adjusted. If there is correlation between the received current on 1 and the interference on 3, an adjustment of the feed-back is indicated.

The scheme shown in Fig. 2 is directly applicable to systems employing four current values. A discussion will now be given of the extension of the same principles to other systems.

Fig. 5 shows the application to eight magnitudes. It will be seen that seven marginal relays are employed and that the feed-back circuit consists of three branches instead of two as in Fig. 3. The first two branches may be arranged as in Fig. 3, namely, so that the first branch determines whether the current fed back shall be positive or negative and the second determines whether the magnitude transmitted should be one or three units. The third branch determines whether a positive or negative current of half unit strength is to be added. The received current is separable into three circuits, I, II and III, in a manner which will be apparent from Fig. 5. The condition shown corresponds to the strongest space current. For the next strongest current, the relay nearest the plate is reversed and there is a consequent reversal in circuit III. Similarly, for the next current value, the second relay from the plate is reversed as is circuit II. For the next highest value, the next relay is operated and circuit III is reversed to the condition shown.

It will be obvious how the system shown in Fig. 5 can be extended to obtain four circuits from a line capable of keeping 16 magnitudes separate, and, in general, n circuits from a line capable of transmitting 2^n distinct magnitudes, where n is a positive integer.

When the number of magnitudes transmitted is not a power of 2, it is not possible to obtain separation as simply as this. I may assume in this case that a single receiving device making use of all the magnitudes is employed. The complexity of such a device need not concern us. It is, however, possible to make use of a feed-back circuit on the principles described as will now be made clear. For the purpose of explanation, it will be sufficient to take the case of five magnitudes. These magnitudes may conveniently be represented in the plate circuit as the five lowest current values in Fig. 5. Under these conditions, the arrangement in Fig. 5 would function to provide the proper feed-back current, the only peculiarity being that the three relays nearest the plate would be permanently on spacing. That being the case, these relays may be removed and permanent connections made to their spacing contacts. (They are shown in Fig. 5 on the marking contacts.) The resulting arrangement is shown in Fig. 6. It will be understood that this figure can be substituted for the upper dotted rectangle in Fig. 5. When this substitution is made, it will be understood that the middle branch of the feed-back circuit will be reversed from the condition shown in Fig. 5.

It will be apparent that the feed-back circuits described can be made to give the proper changes in the magnitude of the current fed back. On the other hand, it may not be obvious that the absolute value is correct. In the arrangement shown in Fig. 6, the current fed back is $-1/2, +1/2, +3/2, +5/2$ or $+7/2$, whereas the current received over the line would reasonably be expected to be symmetrical about zero, i. e., to be $-2, -1, 0, +1$ or $+2$. The explanation is that the constant difference of $1\frac{1}{2}$ units is taken care

of once for all in an initial adjustment such as the adjustment of the grid potential.

A feed-back arrangement employing one branch for each marginal relay may be used instead of the arrangement shown. In the case where the number of magnitudes is three (which is practically an important case) this leads to the arrangement shown in Fig. 7, which is somewhat simpler than that which would be obtained by the method illustrated in Fig. 6.

It should be observed that while in all the cases given the magnitude of the main impulse arriving at the receiver is taken arbitrarily as unity in the middle of its time unit, this is not necessarily the maximum value of the impulse during its time unit; also, while the magnitude of the trailing impulse is taken as minus unity in the middle of the second time unit thereafter, this is not necessarily the maximum value of this trailing impulse. Nor, is it necessary that the maximum value of these two impulses be the same, but only that at the middle of their respective time units they shall be of unit magnitude and opposite in sign.

In using the term unit magnitude throughout this specification it is to be understood that the unit is purely arbitrary and not necessarily equal or simply related to any of the units commonly accepted in the art. Also, in speaking of the n th time unit it is understood that the origin of time may be taken such that the middle of the time unit at the receiving end corresponds to that characteristic point of the main received impulse which is to be used for operating the receiving apparatus. Physically this middle of the time unit may not necessarily be at the middle of the main received impulse, but the shifting of the time origin for purposes of describing this invention will nevertheless bring one to the desired point in that impulse.

Throughout the specification emphasis has been laid on the square topped wave. This has been largely for the purpose of expressing the invention in a relatively simple mathematical form, and while the preferred form of transmitted signaling is a square topped wave, or substantially one, it is to be understood that the invention is not so limited, but the elemental transmitted impulse may take on any desired form. Whatever this form may be the characteristics of the cable and its associated net-works will then have to be arranged to yield a train of impulses at the receiving station which can be used in substantially the way described above. Furthermore, while again for simplicity, both in description and operation, I prefer to arrange the characteristics such that the main impulse is of unit magnitude in the middle of its time unit, and the magnitude of the impulse two units later is equal but of opposite sign in the middle of its time unit, and is zero in the middle of all other time units, the invention is not limited in this way. More broadly, it may be stated that if m_0, m_1, m_2 , etc., are the magnitudes of the impulses in the middle of successive time units, then the conditions to be fulfilled are:

$$(1) m_0 + m_2 + m_4 + \dots = 0$$

and

$$(2) m_1 + m_3 + m_5 + \dots = 0$$

In general, this means that more than three time units have to be considered. If m_0 represents the magnitude of the main impulse in the middle of its time unit, then the feed-back arrangement must be such that impulses of $-m_1, -m_2, -m_3$, etc., are fed back in the middle of

the corresponding time units to neutralize the corresponding impulses. The simplest arrangement and the preferred one, is specifically that in which m_2 is equal and opposite to m_0 , and each of the other impulses is zero at the middle of its time unit.

What is claimed is:

1. In a cable signaling system the method of signaling which consists in transmitting over the cable an impulse element of a unit time duration receiving it as a train of impulses of magnitude m_0, m_1, m_2 , etc., in the middle of the n th, $(n+1)$ th, $(n+2)$ th, etc., time units, the magnitudes being so related that the algebraic sum of the magnitudes of even subscripts equals zero and the algebraic sum of the magnitudes of odd subscripts equals zero, and every magnitude previous to m_0 shall be equal to zero in the middle of its time unit.

2. In a cable signaling system the method of signaling which consists in transmitting over the cable an impulse element of a unit time duration receiving it as a train of impulses of magnitude m_0, m_1, m_2 , etc., in the middle of the n th, $(n+1)$ th, $(n+2)$ th, etc., time units, the magnitudes being so related that the algebraic sum of the magnitudes of even subscripts equals zero and the algebraic sum of the magnitudes of odd subscripts equals zero, and every magnitude previous to m_0 shall be equal to zero in the middle of its time unit, and introducing with the received wave locally generated impulses equal and opposite to the impulses subsequent to the m_0 impulse.

3. In a cable signaling system, the method of signaling which consists in transmitting over the cable an impulse element of a unit time duration, receiving it as a train of unit magnitude in the middle of the n th time unit, of a substantially equal opposite magnitude in the middle of the $(n+2)$ th time unit, and zero magnitudes in the middle of other time units.

4. In a cable signaling system, the method of signaling which consists in transmitting over the cable an impulse element of a unit time duration, receiving it as a train of unit magnitude in the middle of the n th time unit, of a substantially equal opposite magnitude in the middle of the $(n+2)$ th time unit, and zero magnitude in the middle of other time units, and introducing with the received wave a locally generated impulse in the $(n+2)$ th time unit equal and opposite to that coming from the cable.

5. In a cable signaling system, a cable incapable of transmitting direct current and capable of transmitting alternating current only up to frequency s , the method of signaling with a speed of s dots per second which consists in transmitting impulses of duration $\frac{1}{2s}$, modifying the transmission characteristics of the system so that the current value due to a single sent impulse consists of a unit magnitude in the middle of one time unit, zero in the middle of the next time unit, a trailing opposite unit magnitude in the middle of the third time unit, and zero in the middle of all other time units, locally generating impulses which are triggered by the arrival of the impulse in the first time unit, and impressing this generated impulse on the receiver two time units subsequent to the triggering impulse to neutralize the trailing impulse.

6. In a cable signaling system, a cable incapable of transmitting direct current and capable of transmitting alternating current only up to

frequency s , the method of signaling with a speed of s dots per second which consists in transmitting impulses of duration $\frac{1}{2s}$, modifying the trans-

mission characteristics of the system so that the characteristic interference occurs chiefly in the period two time units behind the main signal and is zero in the middle of all other time units and neutralizing the characteristic interference by properly timed and sized locally generated impulses at the receiver.

7. In a cable signaling system, a cable incapable of transmitting direct current and capable of transmitting alternating current only up to frequency s , the method of increasing the number of current magnitudes which can be used on the cable which consists in concentrating the characteristic interference chiefly in a time unit subsequent to the arrival of the main impulse and neutralizing the characteristic interference by impulses generated at the receiver and triggered by the main impulse.

8. The combination of claim 5 characterized by the fact that the neutralizing impulse is timed to come in the time unit in which the interference is concentrated.

9. In a cable signaling system for signaling over a cable which is adjusted by equalizers to give at the receiving end an impulse of the same sign as the sent impulse followed by a trailing equal impulse of the opposite sign, the method which consists in sending from the receiving end into the receiver an impulse to neutralize the trailing impulse.

10. In a submarine signaling system comprising a cable incapable of transmitting direct current or alternating current above frequency s , the method of maintaining correct response to a sustained series of signals of frequency s which die down to zero current at the receiver which consists in sending impulses from the receiver into the receiver until the termination of the zero current condition which results from the continuation of the signals.

11. In a cable signaling system, a cable, a transmitter and a receiver, means for impressing a sustained series of signals on the cable whose steady state value at the receiver is zero, a feed-back circuit at the receiver which is set into operation by and in accordance with the transients at the beginning of the series, the feed-back causing the receiver to operate in accordance with the sent impulses so long as the sent impulses produce a zero current condition at the receiver.

12. In a cable signaling system, a cable, a transmitter and a receiver, means for impressing a sustained series of signals on the cable whose steady state value at the receiver is zero, a feed-back circuit at the receiver which is set into operation by and in accordance with the transients at the beginning of the series, the feed-back causing the receiver to operate in accordance with the sent impulses until the arrival of

a transient due to a change at the transmitter end.

13. In a cable signaling system, a cable and a transmitter adapted to impress thereon an impulse, means to modify the transmission characteristic of the cable such that the received impulse consists of an impulse of the same sign as the transmitted impulse followed by a substantially equal trailing impulse of the opposite sign, means at the receiving end to impress on the receiving apparatus an impulse to neutralize the trailing impulse.

14. In a cable signaling system, a cable and a transmitter adapted to impress thereon an impulse, means to modify the transmission characteristic of the cable such that the received impulse consists of an impulse of the same sign as the transmitted impulse followed by a substantially equal trailing impulse of the opposite sign, means at the receiving end responsive to the first received impulse to impress on the receiving apparatus an impulse to neutralize the trailing impulse.

15. In a cable signaling system, a cable and a transmitter adapted to impress thereon an impulse, means to modify the transmission characteristics of the cable such that the received signal element is spread out over and is substantially contained within three time units and of magnitude $+1$ at the middle of the first time unit, zero at the middle of the second time unit, and -1 at the middle of the third time unit, and means at the receiving end to impress on the receiving apparatus an impulse to neutralize the portion in the third time unit.

16. In a cable signaling system, a cable, equalizing networks attached thereto of such value that the overall transfer admittance of the cable and equalizers shall be given by

$$Y = i \frac{\omega}{4s} \cos \frac{\omega}{4s}$$

where s is the maximum speed of signaling for the cable.

17. In a cable signaling system comprising a cable and a terminal station at each end thereof, a distributor at one end for impressing signals on the cable in accordance with a message to be transmitted, equalizers attached to the cable of such characteristics as to cause the impulse impressed at the sending end to arrive at the receiving end as a main impulse followed by a trailing impulse of substantially equal and opposite magnitude, a distributor at the receiving end operating synchronously with the transmitting distributor, a feed-back relay circuit controlled by the received impulses to impress on the receiver impulses equal and opposite to a trailing impulse, and means for adjusting the delay of the feed-back circuit to cause the neutralizing impulse to be impressed at the time of arrival of the trailing impulse.

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