

March 12, 1929.

H. NYQUIST

1,704,806

SIGNALING SYSTEM

Filed June 11, 1927

2 Sheets-Sheet 1

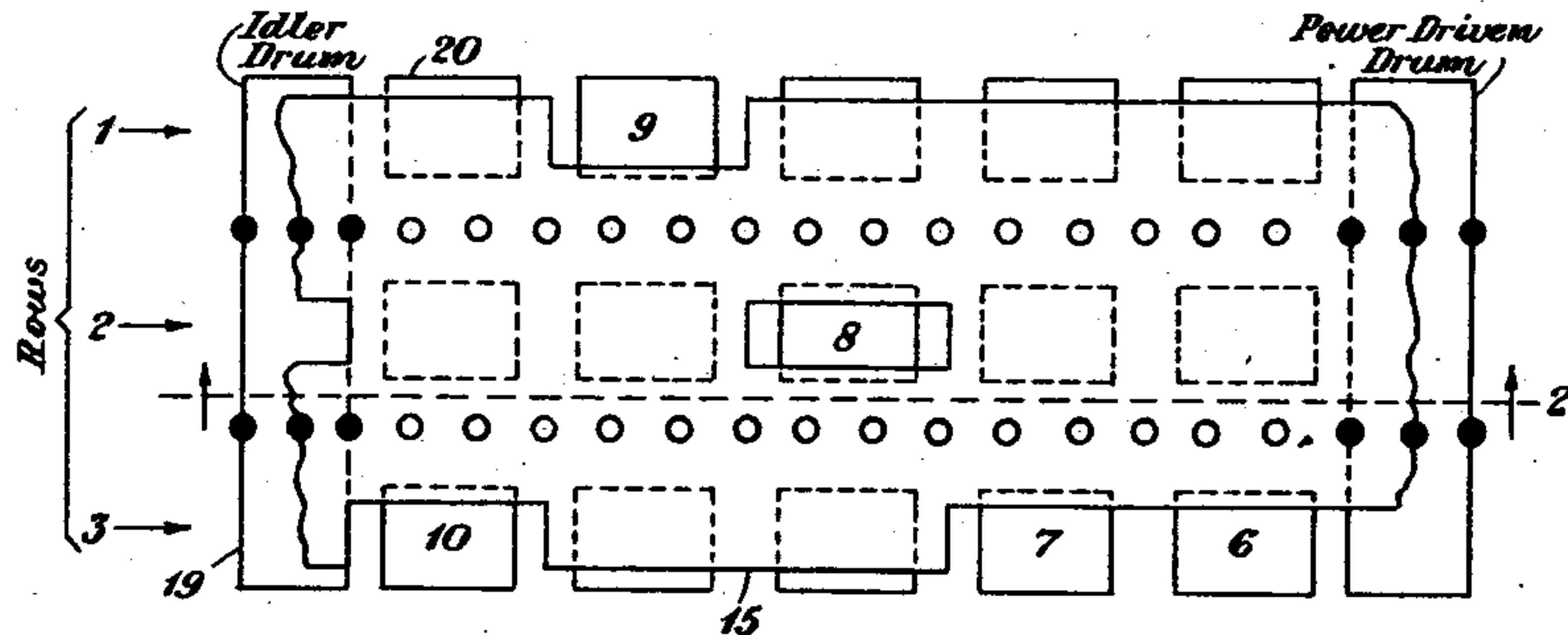


Fig. 1

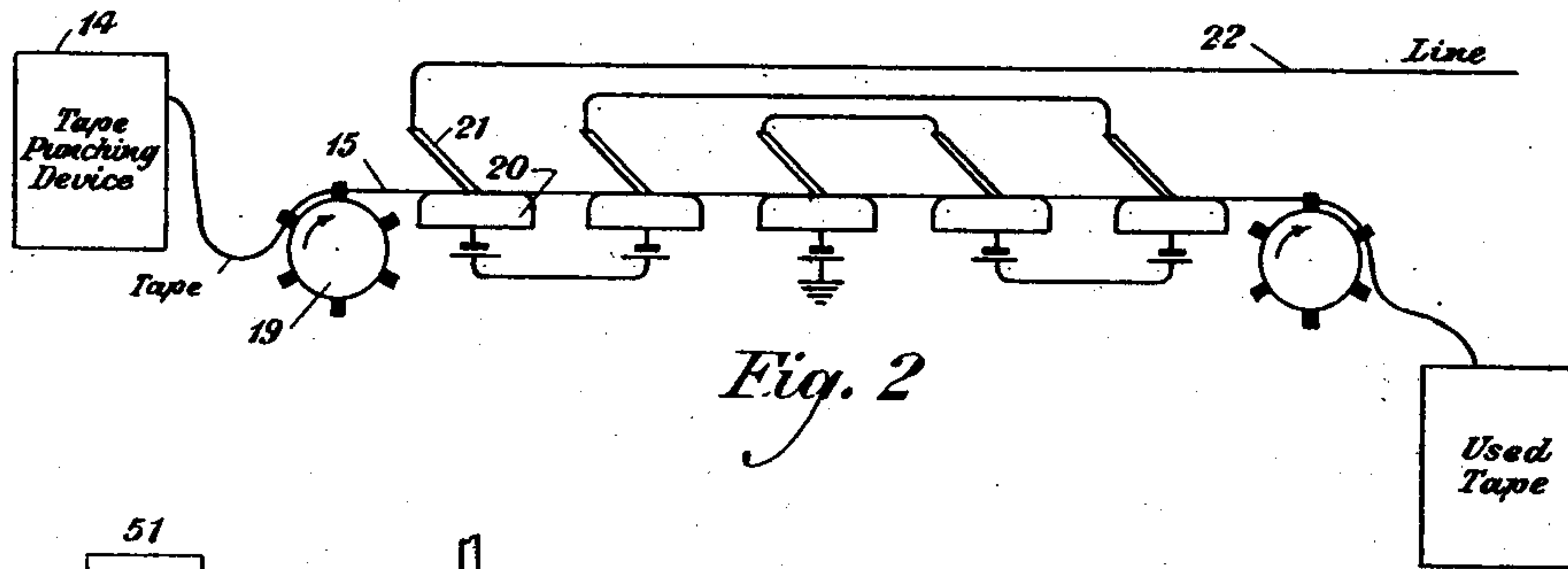


Fig. 2

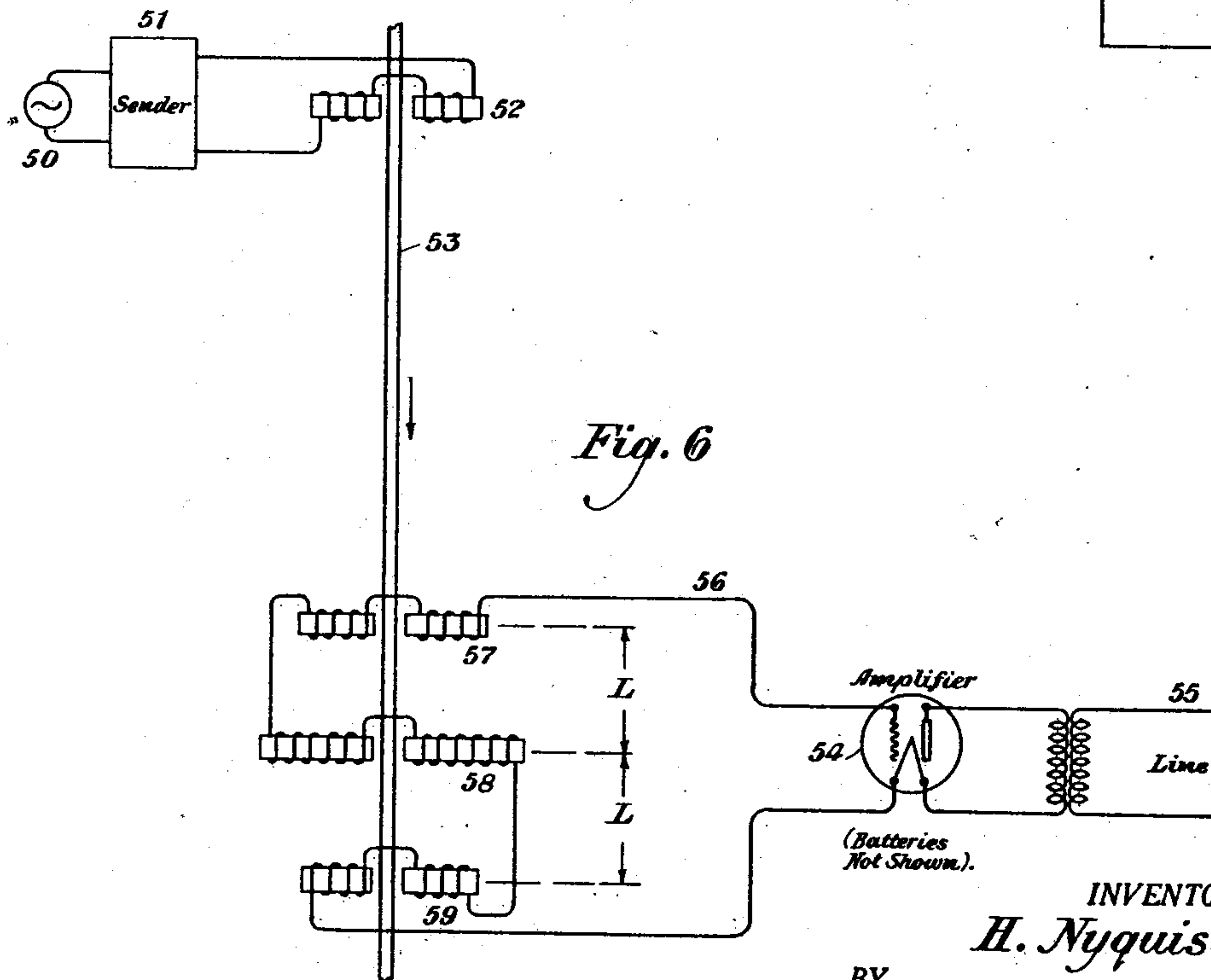


Fig. 6

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2 Sheets-Sheet 2

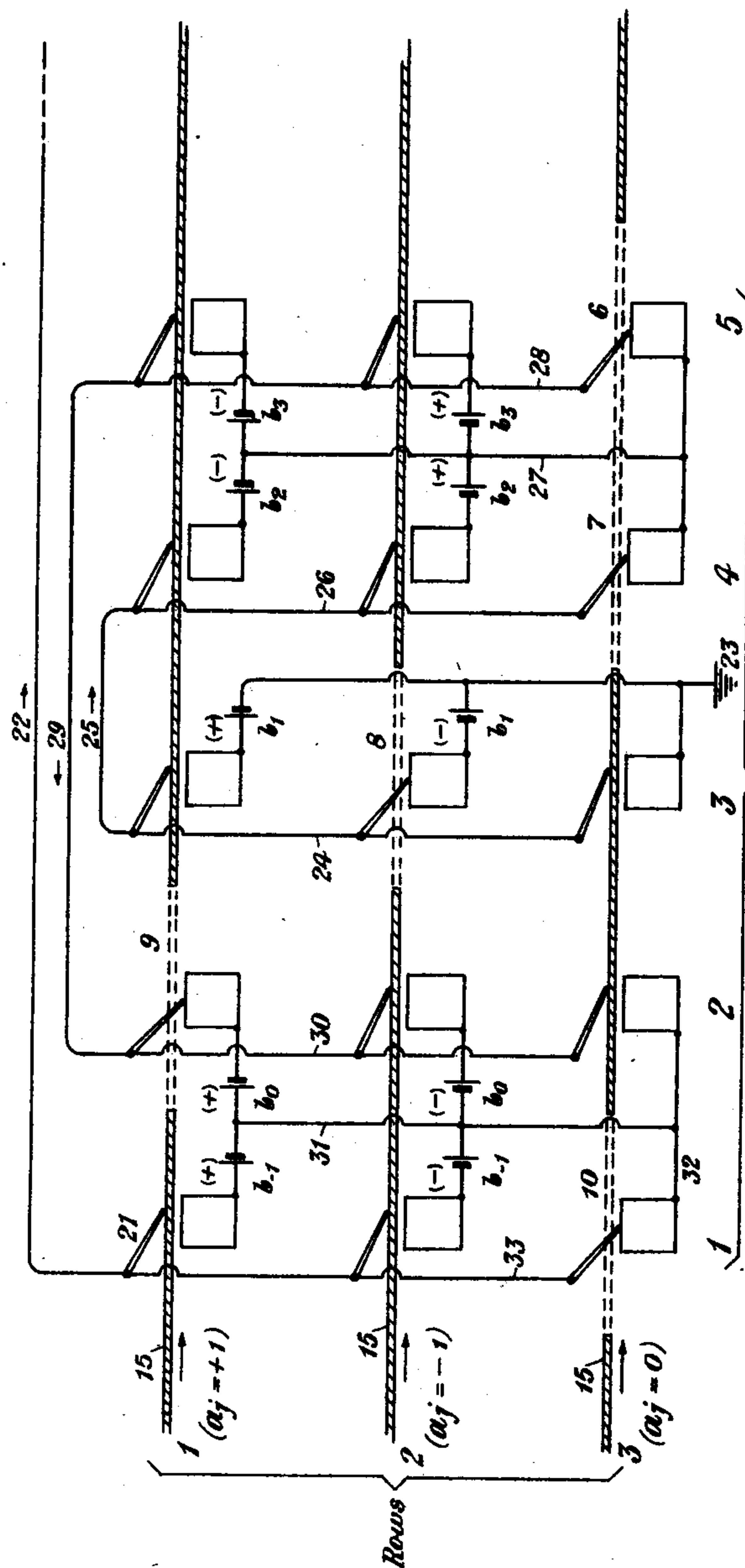


Fig. 3

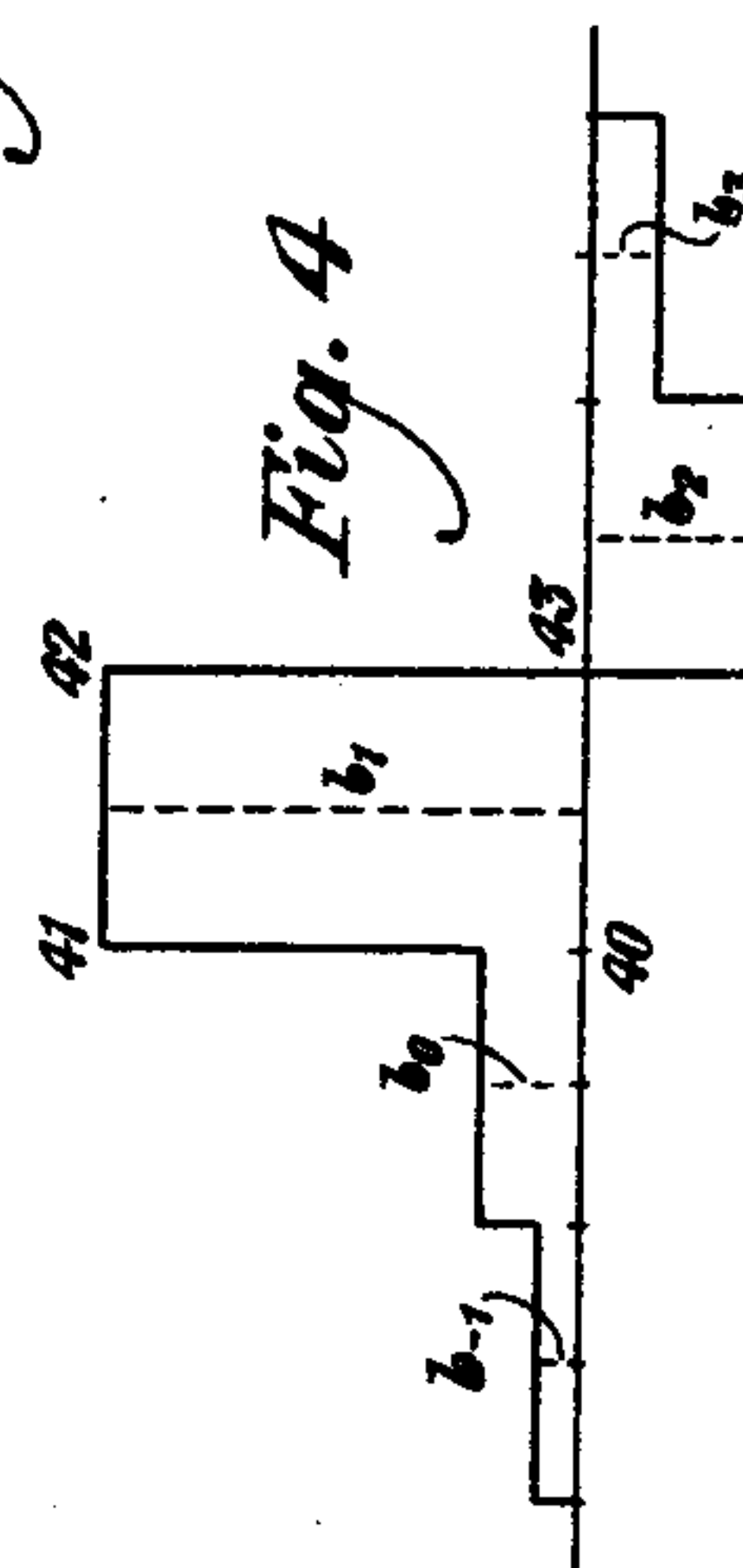


Fig. 4

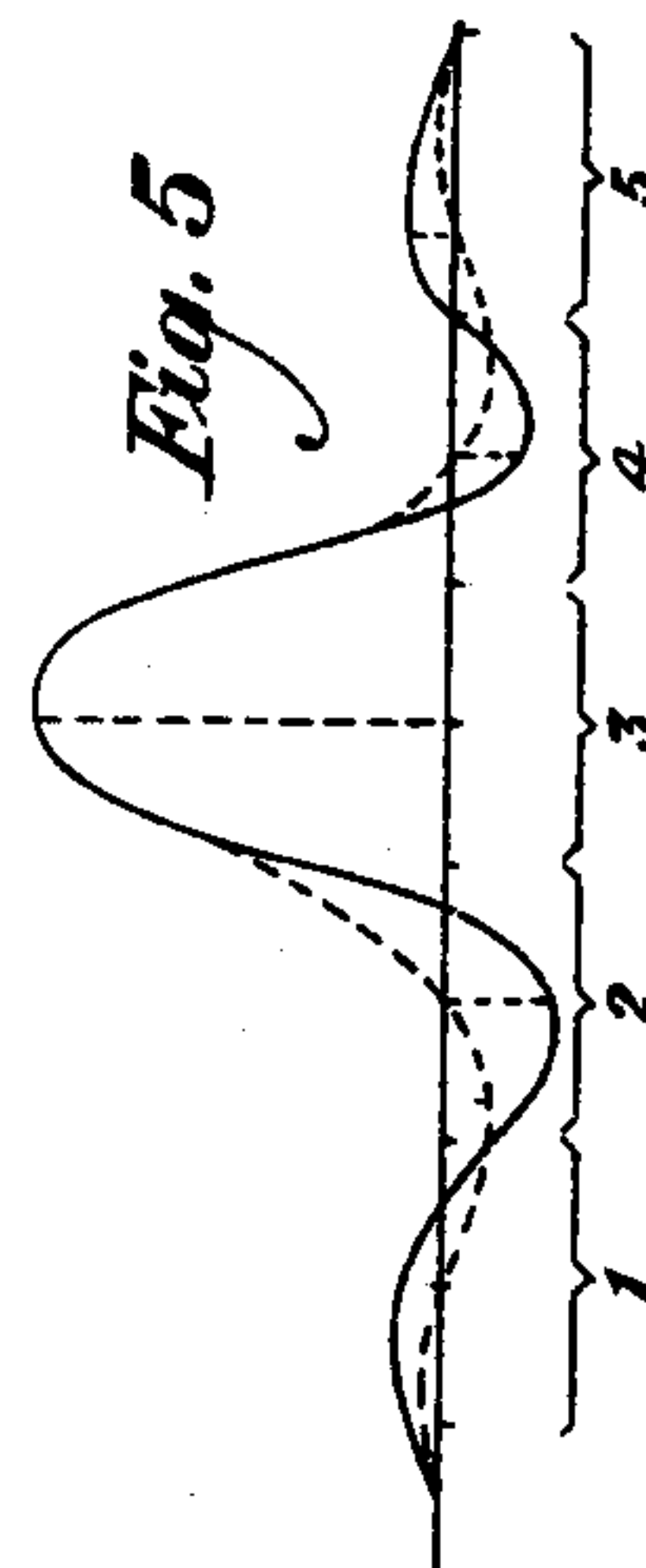


Fig. 5

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1,704,806

UNITED STATES PATENT OFFICE.

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SIGNALING SYSTEM.

Application filed June 11, 1927. Serial No. 198,284.

A principal object of my invention is to provide a new and improved method of signaling in which the signal impulses at the sending end are modified to overcome distortion that would otherwise be present in the signals at the receiving end. Another object of my invention is to provide suitable apparatus for the practice of this method. In one aspect, my invention involves sending a main signal impulse in the midst of a series of auxiliary signal impulses, of which those before and after are to correct at the receiving end for the spread of the main signal impulse and the resulting interference of the signals one with another. Thus, in each time interval for a signal element, there are a number of impulses superposed at the sending end, each belonging to the series for a respective complete signal. These objects and aspects of my invention and other objects will become apparent on consideration of a limited number of specific examples of practice of the invention which I have chosen for disclosure in the following specification. It will be understood that this disclosure relates to these particular examples of the invention and that the invention will be defined in the appended claims.

In the drawing, Figure 1 is a diagrammatic top plan view of sending apparatus, with the brushes removed; Fig. 2 is a side elevation, partly in section along the line 2—2 of Fig. 1; Fig. 3 is a diagram with the sending tape split apart into three sections to facilitate showing the circuits completely; Fig. 4 is a diagram for a complete signal element at the sending end; Fig. 5 is a diagram for received signal waves, the heavy curve corresponding to no signal shaping and the dotted curve to the sent wave shown in Fig. 4; and Fig. 6 is a diagram for a modification involving the use of carrier currents.

In the assumed system, as shown in Figs. 1 to 5, there are to be three different distinguishable current or electromotive force strengths at the receiving end proportional to +1, -1 and 0. That is, letting a_j be the amplitude factor, then $a_j = +1, -1$ or 0. The sending tape 15 is punched in three rows of holes or notches along its length corresponding to these three values of the amplitude factor. These three rows of holes or notches are indicated (see Figs. 1 and 3) by the arrows 1 for $a_j = +1$, 2 for $a_j = -1$ and 3 for $a_j = 0$. Hereafter, when I refer to a hole in the tape

15, I will mean a hole or a notch as the case may be. The section of tape shown in the drawings is punched at 6, 7, 8, 9 and 10 for the following values of the amplitude factor a_j , successive in time, namely 0, 0, -1, +1, 0.

The message is punched in the tape 15 according to the code employed; this is done in the apparatus 14 from which the tape passes around the idler drum 19 and over the contact blocks 20, of which there are three rows of five each. The blocks 20 in a row may be distinguished as in five different columns as indicated at the bottom of Fig. 3. The respective rows of contact blocks 20 correspond to the respective rows of holes in the tape, that is, rows 1, 2 and 3. Over each block 20 is a corresponding brush 21, so that as a hole in the tape 15 moves along, it causes five successive contacts between the successive blocks 20 of a row and their corresponding brushes 21.

Batteries are connected with certain of the blocks and the connections are such that the contacts between the blocks 20 and brushes 21 causes certain of these batteries to be applied in series to the line 22. The corresponding electromotive force on the line is composite, with its components due to the respective batteries connected in series. Although there are no batteries connected with the blocks 20 for row 3, we may say that these blocks have batteries of zero strength; this will facilitate discussion. The third or middle contact block of each row, that is, the block in column 3, has a battery of proper strength to put what may be called the main electromotive force component on the line for the signal corresponding to a hole in that row. The first, second, fourth and fifth blocks of the same row have batteries of certain strengths (generally of less magnitude than for the battery for the third block) which when connected in series on the line put on respective components of electromotive force that may be called auxiliary components. The matter of battery strengths for the auxiliary components will be discussed later. For the present, it may be noted that the battery strengths have the values indicated by the legends on the drawings, b 's each with a certain subscript.

With the circuit connections as shown in Fig. 3, we may now proceed to trace the circuit from ground 23 to line 22. According to the code system, there will be one and only

one hole in a column of the tape. Hence, coming from ground 23 there will be one and only one path to a brush in column 3. In the particular instance shown in Fig. 3, this is the hole 8, hence battery $-b_1$ is in circuit, in the direction in which the circuit is being traced. Proceeding along conductors 24, 25 and 26, the one and only hole in column 4 is at 7 which connects zero battery in circuit. Proceeding along conductor 27 we reach the one and only hole in column 5 at 6, which again includes zero battery in circuit. Thence following along conductors 28, 29 and 30, we find the one and only hole in column 2 at 9 which includes battery $+b_0$ in circuit. Thence we proceed along conductors 31, 32 through hole 10 (which adds zero battery) and conductor 33 to line 22. In order from ground 23 to line 22, the battery strengths in the circuit are $-b_1+0+0+b_0+0$. In the same order, the connections are made through respective contact blocks 20 of columns 3, 4, 5, 2, 1.

As the hole 9 in the tape 20 moves from left to right it puts on the line successively the five voltage magnitudes b_{-1} , b_0 , b_1 , b_2 and b_3 . Hence the component of the applied electromotive force due to the hole 9 as a function of time will be a graph like that shown in Fig. 4. If only a single impulse were sent, corresponding to the rectangle 40-41-42-43 in Fig. 4, the corresponding current at the receiving end would spread out and have, for example, the general wave form shown by the heavy line in Fig. 5. The amplitude of this wave at any instant depends on the nature of the line. It approaches zero eventually and in the present example, it approaches zero fairly rapidly so that it is sufficient to consider only that part of the wave which extends over five signal elements. What is desired for receiving is a substantial ordinate such as at the mid-point of the third time interval, but the ordinates at the mid-points of time elements 1, 2, 4 and 5 are objectionable as they interfere with the signal elements intended to be received in those time elements. Hence, proper values are given to b_{-1} , b_0 , b_1 , b_2 and b_3 in Fig. 4 for the sending end, to make the ordinates at 1, 2, 4 and 5 all reduce to zero at the receiving end, as indicated by the dotted line curve in Fig. 5.

For the computation of the b 's the following formula may be employed:

$b_j = \text{real part of}$

$$\frac{1}{2\pi s} \int_0^{2\pi s} \frac{F_0(\omega) e^{i\omega \left(\frac{j-1}{2s} + \gamma \right)} d\omega}{\sum_{q=-\infty}^{\infty} F_s(4\pi s q + \omega) Y(4\pi s q + \omega) e^{-i4\pi s q \gamma}}$$

This formula is general and will serve for more general step shapes than that indicated in Fig. 4. But for such cases as Fig. 4, that

is for rectangular steps, the symbols in the formula represent the following quantities: s is the line speed, obtained by dividing the number of rectangular signal elements (5 in the example heretofore considered) by twice the time for putting this sequence of elements on the line;

$$F_s(\omega) = \frac{8 \sin \frac{\omega}{4s}}{\omega/s};$$

γ is an arbitrary constant and is of the nature of a constant delay; $Y(\omega)$ is the transfer admittance of the line as a function of ω ; and $F_0(\omega) = 2$.

A suitable value to be assumed for γ may be found by plotting b_1 as a function of γ . From such a plot γ may be chosen to make the number of rectangular steps a minimum. The number of such steps has been taken at 5 in connection with Figs. 1 to 5.

In the computation of b_j by the aid of the foregoing formula, various transformations and other expedients may be employed which I will not set forth here, as they will be apparent to those who understand and are accustomed to such computations.

While the apparatus shown in Figs. 1 to 3 has the contact blocks in only 3 rows and 5 columns, any other suitable number of rows and columns might be employed, the number of rows corresponding to the number of distinguishable signal elements at the receiving end and the number of columns corresponding to the number of distinguishable impulses in succession in respective time elements for each complete signal element as transmitted.

If it is desired to send rectangular steps with curbing, the holes 8 and 9 in the tape 15 may be shortened for this purpose, and corresponding holes may be punched in row 3 of the tape 15 to prevent open circuits.

An application of the principle of my invention in connection with carrier current telegraphy is shown in Fig. 6. Carrier current of a certain frequency is supplied from the generator 50 to the sender 51, where it is modulated by interruption or otherwise to form signal elements, each of the duration of a determined time element. This modulated output current from apparatus 51 goes to magnet 52 and causes the corresponding magnetization of the moving telegraphophone record tape 53. This tape 53 moves with such speed that it goes a distance L during one time element. Hence, each successive length L becomes magnetized to correspond to a corresponding signal element, more particularly a corresponding duration of carrier current modulated to correspond to a respective signal element.

The magnets 57, 58 and 59 are spaced along the tape 53 at distance intervals L . They are in series in the grid circuit 56 of a three-

electrode vacuum tube 54 whose output circuit is operatively associated with the line 55. Whereas, 5 steps of electromotive force values were assumed for the system of Figs. 1 to 5, here three steps are assumed; call them b_{-1} , b_0 and b_1 . The magnets 57, 58 and 59 are so designed that their ratios of turns to reluctance are respectively proportional to b_{-1} , b_0 and b_1 . Then when an alternating carrier current pulse of amplitude a_r and one time element in duration is applied to magnet 52, the resultant induced voltage due to magnets 57, 58 and 59 acting on the grid of amplifier 54 will have an envelope in three rectangular steps proportional respectively, to $a_r b_{-1}$, $a_r b_0$ and $a_r b_1$. The values of the b 's are adjusted so that at the receiving end there is compensation for the spread of each main signal element into the time intervals for antecedent and subsequent signal elements, according to the principles indicated heretofore in this specification.

When it is desired to produce waves with rectangular stepped envelopes with curbing with the apparatus of Fig. 6, the part of the telegraphone record tape 53 associated with

magnets 57, 58 and 59 may be caused to pause a short duration of time at the end of each signal element time interval, or the curbing may be applied in the apparatus 51. 30

The foregoing examples of practice of my invention are based on the following assumed criterion of distortionless transmission which we may call Criterion A, namely that the ordinate of the received wave when recorded by the receiving device at the middle of each time element as representative of the original for that element shall be proportional to a corresponding signal element at the sending end. 35 40

Another alternative Criterion B of distortionless transmission that may be considered is as follows: that the interval between the instants when the received current passes through the mean value shall be the same as the corresponding interval at the transmitting end. Yet another alternative Criterion C is the following: that the area under the received wave shall have the same value as under the sent wave during each signal element. 45 50

For Criterion B, the formula for the b 's is

$$b_j = \text{real part of } \frac{1}{2\pi s} \int_0^{2\pi s} \frac{F_o(\omega) \cos \frac{\omega}{4s} e^{i\omega \left(\frac{j}{2s} + \gamma \right)} d\omega}{\sum_{q=-\infty}^{\infty} (-1)^q F_s(4\pi s q + \omega) Y(4\pi s q + \omega) e^{-i4\pi s q \gamma}}$$

Where $F_o(\omega) = 2 \cos \omega/4s$ for rectangular steps

55 $F_s(\omega) = 8 \frac{\sin \omega/4s}{\omega/s}$ for rectangular steps

Here b_j is the height of the middle of the j th step.

For Criterion C,

$$b_j = \text{real part of } \frac{1}{8\pi s^2} \int_0^{2\pi s} \frac{F_o(\omega) e^{i\omega \left(\frac{j-1}{2s} + \gamma \right)} d\omega}{\sin \frac{\omega}{4s} \sum_{q=-\infty}^{\infty} F_s(4\pi s q + \omega) Y(4\pi s q + \omega) e^{-i4\pi s q \gamma}}$$

60 Where $F_o(\omega) = \frac{\omega/2s}{\sin \omega/4s}$ for rectangular steps

$F_s(\omega) = \frac{8 \sin \omega/4s}{\omega/s}$ for rectangular steps.

65 Here again, b_j is the height of the middle of the j th step.

I claim:

1. The method of telegraph signaling which consists in sending a main signal impulse in one time element with auxiliary impulses in neighboring time elements both before and after said one time element and making these auxiliary impulses of proper magnitudes to correct for distortion at the receiving end. 75

2. The method of telegraph signaling which consists in sending waves of stepped rectangular contour with the amplitudes in the respective steps of proper magnitude to correct for distortion at the receiving end. 80

3. The method of telegraph signaling with respective signal elements for respective time elements, which consists in extending each signal element into neighboring time elements both earlier and later with proper magnitude to correct for distortion at the receiving end. 85

4. The method of sending signals from a tape record which consists in sending successive impulses for each element of the tape record whereby each transmitted impulse is 90

of composite value determined by several tape record elements.

5. The method of sending signals from a tape record which consists in sending successive impulses for each element of the tape record whereby each transmitted impulse is of composite value determined by several tape record elements, certain of the successive impulses determined by each tape record element being made of such magnitude values as to correct for distortion at the receiving end.

6. The method of telegraph signaling which consists in sending waves of stepped rectangular contour, each step corresponding to a time element, and there being one such wave for each time element, thereby overlapping the successive waves, and making the overlapping parts of such magnitude as to correct for distortion at the receiving end.

7. The method of telegraph signaling with respective signal elements for respective time elements, which consists in extending each signal element into neighboring time elements both before and after, the extended portions being given such values that at the receiving end they produce null values in the corresponding extended parts of the received signal wave.

8. The method of telegraph signaling which consists in sending for each signal element a signal wave comprising a first part, a main part and a last part, the first and last parts having the proper values to give null effects in the corresponding parts at the receiving end whereby at the receiving end only the part corresponding to the main part will be effective.

9. Apparatus for telegraph signaling consisting of a tape record with respective records for signal elements along its length, a

line, and means to put successive impulse components on the line for each signal element record, whereby the resultant impulses on the line will comprise components corresponding to several different signal elements.

10. Apparatus for telegraph signaling consisting of a line, sources of different strengths for impulses to be applied to the line, and means operatively to connect these sources to the line in succession for each signal element and in part simultaneously for consecutive signal elements.

11. Apparatus for telegraph signaling consisting of a tape record with respective records for signal elements along its length, a line, and means to put a main impulse component on the line for each signal element record and to put auxiliary impulse components on the line for the same signal element record but in the neighboring time elements, whereby the resultant impulses on the line will comprise components corresponding to several different signal elements.

12. Apparatus for telegraph signaling consisting of a tape record with respective records for signal elements along its length, a line, and means to put a main impulse component on the line for each signal element record and to put auxiliary impulse components on the line for the same signal element record but in neighboring time elements, whereby the resultant impulses on the line will comprise components corresponding to several different signal elements, and each main signal impulse will be received with null effect from neighboring signal impulses.

In testimony whereof, I have signed my name to this specification this 9th day of June 1927.

HARRY NYQUIST.