

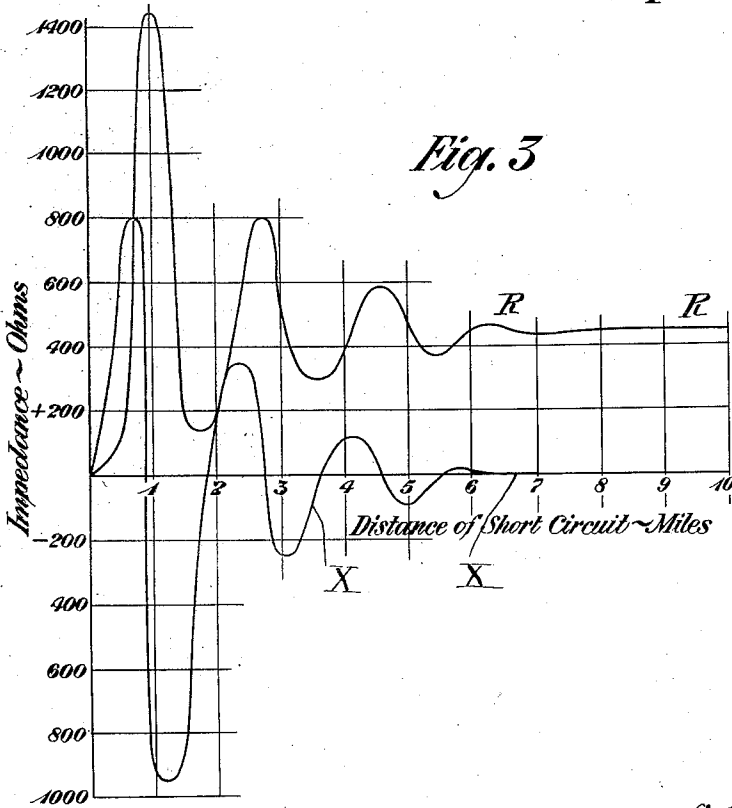
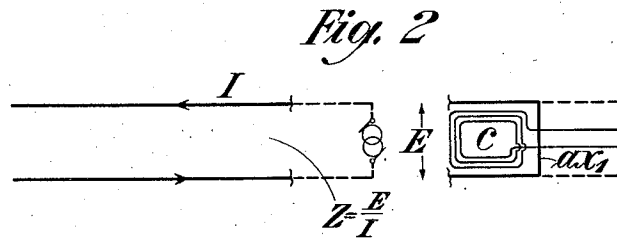
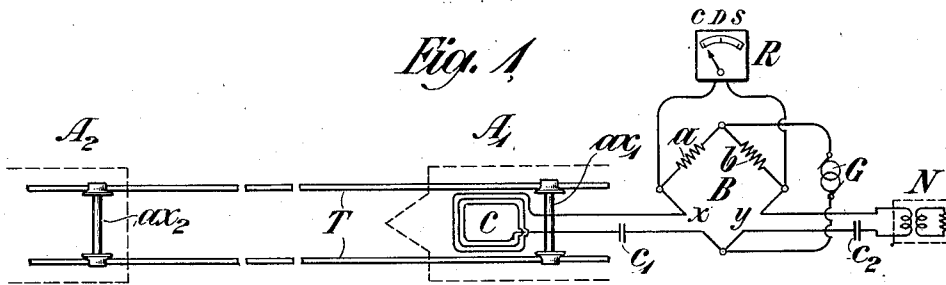
Dec. 2, 1924.

1,517,549

L. ESPENSCHIED  
RAILWAY SIGNAL SYSTEM

Filed Nov. 21, 1919

4 Sheets—Sheet 1



INVENTOR

*L. Espenschied*

Dec. 2, 1924.

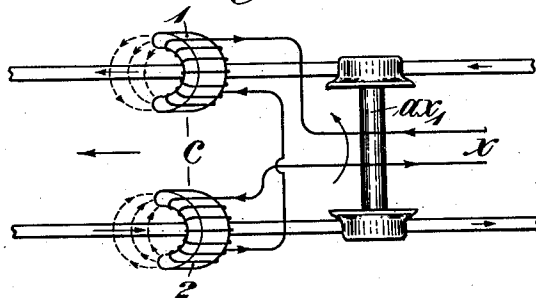
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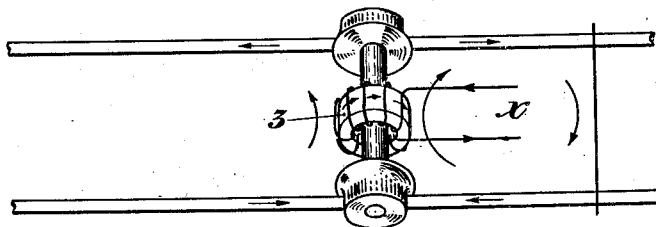
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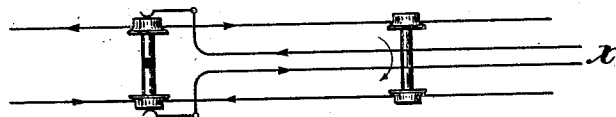
*Fig. 4*



*Fig. 5*



*Fig. 5-a*



INVENTOR

*L. Espenschied*

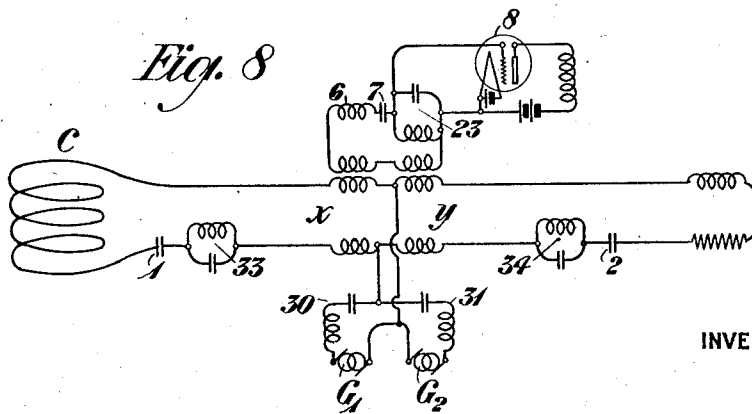
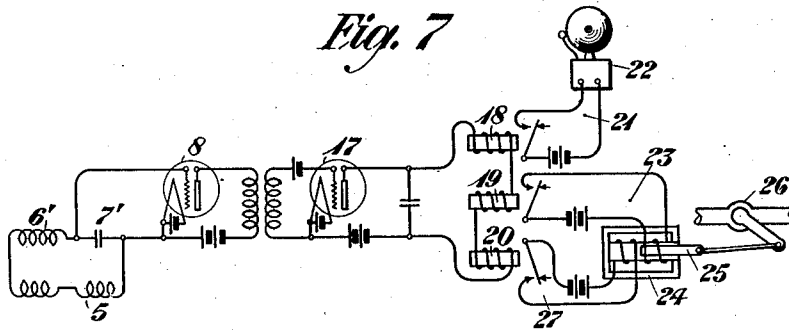
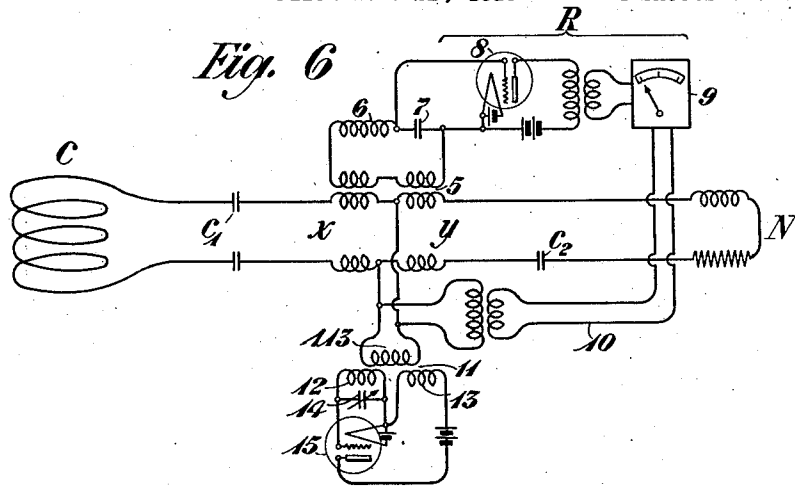
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RAILWAY SIGNAL SYSTEM

Filed Nov. 21, 1919

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INVENTOR

*L. Espenschied*

Dec. 2, 1924.

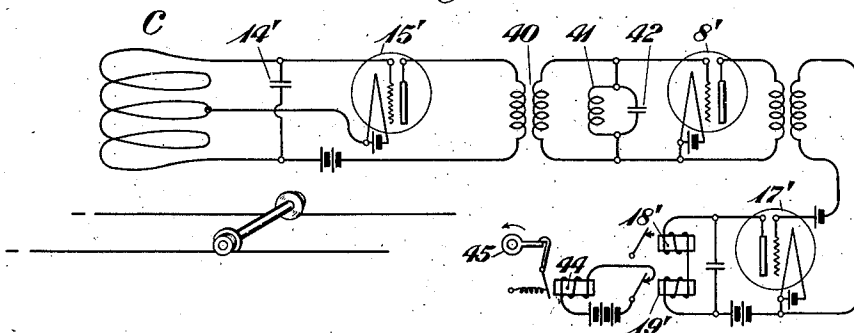
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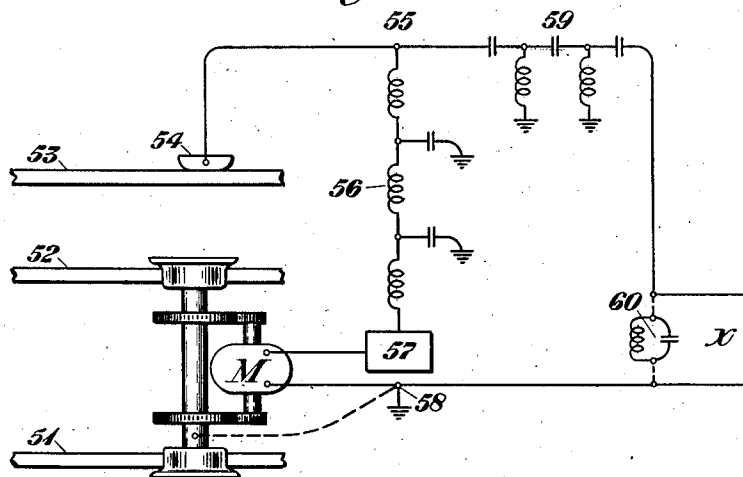
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*Fig. 9*



*Fig. 10*



INVENTOR

*L. Espenschied*

# UNITED STATES PATENT OFFICE.

LLOYD ESPENSCHIED, OF QUEENS VILLAGE, NEW YORK.

## RAILWAY SIGNAL SYSTEM.

Application filed November 21, 1919. Serial No. 339,658.

*To all whom it may concern:*

Be it known that I, LLOYD ESPENSCHIED, a citizen of the United States, residing at Queens Village, in the county of Queens State of New York, have invented certain Improvements in Railway Signal Systems, of which the following is a specification.

This invention relates to railway signaling systems. More particularly it provides means for indicating, as in an engine cab, the condition of the track ahead.

The invention is directed at promoting safety in railroad operation. One object is to provide a signaling system which does not require sectionalizing the track and the provision of signaling mechanisms along the right of way as does the block type of signal system, but which enables the equipment to be entirely localized and placed aboard a locomotive. A further object is to increase the certainty on the part of the engineer of correctly seeing the signal by having the same set up in the engine cab instead of along the right of way. A still further feature of the present system is that it is not only capable of indicating the condition of the track ahead, but also of controlling automatically in accordance therewith the headway of the train and of bringing it to a stop under conditions of danger. Further and more detailed objects of the invention will be evident from the disclosure following.

To facilitate a comprehensive understanding of the invention there is given first an outline of the broader principles of the method and means involved.

In accordance with the present invention the railway signal is controlled by sending out wave energy from the signal location through transmission circuits in the right of way and causing this outgoing energy to effect, in accordance with traffic conditions, the return or non-return to the signal of energy for controlling the signal. According to the invention therefore there are two separate and distinct energy transmissions—an outgoing wave and a returning wave, the latter being dependent on the former and the control of the signal being effected thereby.

In the preferable forms of embodiment of the invention, the track rails are utilized as the conductors for both the outgoing and the returning energy waves, suitable appa-

ratus being employed to discriminate between the waves at the signal location. If the signal is to be given in the engineer's cab, the wave energy is impressed on the track preferably by a source of energy located in the locomotive so that expensive wayside equipment is minimized.

The returning energy wave may be set up in any suitable manner. The method particularly described herein utilizes as a fundamental principle the reflection of electric energy waves, but it is to be expressly understood that the invention is not limited thereto. This method has the important advantage, however, of requiring no instrumentalities in the trackway or on the train for originating the returning energy wave, as will be described more in detail hereinafter.

When electric wave energy is impressed on an infinitely long transmission circuit or line whose electrical constants; inductance, resistance and capacity per unit of length of the line, are substantially the same or uniform throughout, the waves of energy impressed thereon flow uniformly along the line, generally becoming smaller and smaller in amplitude because of the attenuating effect of the circuit. If the length of the line is finite, however, the waves upon reaching the distant terminal of the line will encounter an irregularity (unless apparatus having the identical electrical constants is associated therewith), which irregularity has the effect of causing part of the current wave to be reflected to the sending end of the line. This phenomenon is similar to that of the reflection of light and sound waves when such waves traveling in one medium, encounter another medium of different optical or acoustic properties. An echo for example, is produced when the sound waves traveling in one medium, such as air, encounter another medium of different acoustic properties, such as a wall. Part of the sound waves enter the wall and are absorbed thereby and the remainder is reflected into the air, the ratio between the absorbed and reflected portions depending upon the difference in the sound transmitting properties of the two media, or in other words, the degree of the irregularity encountered by the waves. So it is with waves in an electric transmission circuit or line. At the end of the line there is a reflection

of the current waves, unless the apparatus connected thereto has the same impedance properties, and the amount of reflection depends upon the degree of irregularity encountered by the waves. The reflected waves return to the sending end of the circuit where they may be detected by suitable apparatus. If the circuit is very long, electrically speaking, the reflected waves, however, are so dampened out owing to the attenuation of the line, that they become practically negligible, just as an echo cannot be heard if the reflecting wall is too far away. If the circuit is made shorter and shorter the reflected wave grows stronger and stronger in intensity as it returns to the sending end, similarly as an echo grows louder as the reflecting wall is approached.

In one form of embodiment of the invention the track rails proper constitute the conductors of the transmission circuit or line and a suitable source of current is provided to send out electric waves over the said circuit. When the waves encounter an irregularity in the rail circuit, as for example a break in the circuit, as caused by a broken rail, or a short circuit, such as is caused by the wheels and axles of a train, they are reflected toward the transmitting end, where suitable apparatus is provided for their detection. If the irregularity is far ahead, the waves are very weak, indicating that it is safe to proceed over the track at maximum speed; if nearer, the reflected waves are stronger indicating that caution should be exercised, and if close by, the said waves are of such intensity as to indicate that it is unsafe to proceed.

It will thus be seen that the present invention is characterized by the feature that there are two distinct flows of energy, namely an outward flow which exists irrespective of the traffic conditions ahead of the train and a return flow which is set up only under certain traffic conditions, as for example, the condition of a short circuit by a train in advance or a broken rail, this return flow of energy being segregated by suitable apparatus from the outward flow and being utilized to control the indications of the signal.

The invention thus differs broadly from the prior systems in which electrical energy generated on the train, whether alternating or direct, is passed through an ordinary circuit extending along the right of way, which circuit is controlled by opening and closing it, as by a switch, or by the presence of a second train on the track. Even if in considering such a system the artificial viewpoint is adopted, that the existence or non-existence of the current (according for instance, to the closed or open position of a switch) is caused by reflection at the switch, then it must be recognized that the reflection

exists for both positions of the switch, a short circuit being as truly an irregularity as an open circuit. (This will be apparent by reference to the preceding description of the present invention in which it is shown that a short circuit across the rails sets up reflected waves as well as a break in the rails). Consequently, with reflection occurring for both the open and closed positions of the switch there is no condition in the circuits of the previously proposed systems which corresponds to the clear track condition of the present invention, no provision being made for preventing the return flow of energy to the signal for one condition of signaling, as for example, the clear track condition. As a matter of fact the prior systems do not even recognize the existence of a reflected wave and consequently make no provision for segregating the reflected and outgoing energy waves, much less use the returning wave, as distinguished from the outgoing wave, for controlling the signal.

Another manner in which the present form of embodiment of the invention may be explained consists in considering the "entrant" impedance of the transmission circuit of the line, this impedance being the ratio of the electro-motive force impressed upon, to the current entering, the transmission circuit. Where the circuit is electrically long i. e., many wave lengths long, and of correspondingly high attenuation the "entrant" impedance for an alternating current is substantially independent of the condition at the other end of the circuit, as to whether opened or closed, and is determined solely by the linear constants of the transmission line. For such an electrically long circuit the entrant impedance is called the "characteristic" impedance and is defined by

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

where R is the series resistance per unit length (say per thousand feet), G is the shunt conductance per unit length; L the inductance and C the capacity per unit length; and  $j$  is the vector notation of complex algebra to indicate a phase difference of  $90^\circ$ ; and  $\omega$  indicates  $2\pi$  times the frequency. Computations indicate, for example, that the characteristic line impedance of a clear track, would be of the order of a few hundred ohms pure resistance were the circuit ideal, in the sense of having a negligible series resistance and leakage. Actually of course, the track circuit has series resistance and is characterized by large leakage, so that in practice the characteristic resistance, as above defined, may be of very much smaller value and will have a reactance component.

Where the circuit is not long electrically,

the effect at the sending end of the distant termination will change the value of the "entrant" impedance. This effect may be regarded as caused by the current wave reflected from the distant end which, upon again reaching the sending end, combines with the current then entering the line to change its effective value and thereby alter

the ratio of  $\frac{E}{I} = Z$ . The normal impedance will be increased or decreased depending up the phase relation between the incident and the reflected waves.

The reason that this effect does not occur in a circuit long electrically is that the attenuation or dissipation of such a circuit is so large as to dampen out the reflected wave to such a small value that it does not appreciably affect the current at the originating end. If we take an electrically long circuit and greatly reduce its length, there comes a point at which the reflected wave is returned to the sending end in sufficient amplitude to appreciably affect the resultant sending current and to thereby alter the "entrant" impedance. If we continue to shorten the length of the circuit the reflected wave becomes an increasingly greater factor until at relatively short lengths the "entrant" impedance is determined largely by the reflection effect and in turn by the terminal impedance of the circuit.

The manner in which the characteristic "entrant" impedance of a track circuit varies with the length thereof is illustrated in Figure 3. The curves show the effect of moving a short circuit, such as that caused by a train on a track, from a distance out in toward the point of observation. The impedance values plotted are of the resistance  $R$  and the reactance  $X$  ( $Z = R + jX$ ) for 50,000 cycles impressed metallicly upon the track circuit. Starting at say eight miles out and decreasing the distance, the impedance expressed in terms of resistance and reactance, will be noted to gradually deviate in an oscillatory manner from the normal "clear track" value until, when the short circuit comes within a distance of about one mile, both the resistance and reactance have been greatly altered. The values of the impedance curve of Figure 3 have been computed from the formula:

$$Z = Z_0 \tanh PL$$

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} = \sqrt{\frac{L}{C}} \text{ approx.}$$

$$P = \sqrt{(R + j\omega L)(G + j\omega C)}$$

where  $Z$  is the resultant entrant impedance,  $Z_0$  is the "infinite line" or in this case "clear track" impedance,  $L$ , the length of the circuit and  $P$  is the propagation constant.

The term  $\tanh PL$  represents the effect of the reflected wave at the sending end.

The following values per thousand feet have been assumed, for purposes of illustration, in the computations for the curve of Fig. 3.  $-R = 0.02$  ohms;  $G = 0.001$  ohms;  $L = 0.00045$  hen;  $C = 2.3 \times 10^{-9}$  fds.

It is the impedance characteristic of a transmission circuit as outlined above which is utilized in the present invention for indicating the proximity of two railway trains, one to the other. The section of track between the two trains is treated as an electric transmission circuit, and one train, for instance the oncoming train, is used as the transmitting end of the circuit, and the other train, the "train ahead," is used, by virtue of its effect in short circuiting the rails of the track, as the distant termination of the circuit. The strength and phase relation of the wave reflected from the train ahead back to the oncoming train is used as an indication of the distance apart of the two trains. Thus so long as the separation is so great that the reflected wave, received back at the oncoming train, is of inappreciable amplitude, a signal on said train is set indicating a clear track. When a lesser separation exists, giving an appreciable reflected wave at the oncoming train, and requiring cautious proceeding this condition may be made to indicate caution and, if desired, to slow down the oncoming train. When a still lesser distance and one involving danger of collision, separates the two trains, this condition is made to indicate danger and to effect automatically the stoppage of the oncoming train.

One of the features of the present invention is the use of relatively high frequencies for limiting by virtue of the high attenuation the range or distance ahead to which the signaling system is responsive. By the use of a high frequency the signaling mechanism is rendered unresponsive to and the engineer is not bothered by trains so far ahead as to not constitute a danger. The exact frequency employed is determined by the constants of the circuit employed and by the distance within which it is desired to operate a signal.

The frequency to be employed for any given condition of signaling is determined by computing the reflection effect by formulæ as indicated above, or by measurement of the track or other circuit which is to be used as the transmission circuit, and coordinating such results with the characteristics of the terminal apparatus. It should be understood that while the invention in its preferred form employs frequencies in the radio frequency range, it is not limited in respect to frequency.

Having explained the general principles

involved in the invention and having indicated the method of applying them in a railway signaling system, there are hereinafter described several specific embodiments of the invention.

Figure 1 illustrates diagrammatically one form of the entire signaling system.

Figure 2 indicates the manner of impressing the alternating E. M. F. upon the track circuit and has reference to the "entrant" impedance characteristic of the track circuit which as indicated in Figure 3 is the basis of operation of the invention.

Figures 4, 5 and 5<sup>A</sup> show details of means for making connection between the track circuit and the local apparatus.

Figure 6 illustrates an alternative form of the local circuit arrangements.

Figure 7 illustrates the use of an alarm and control circuit.

Figure 8 shows a local circuit arrangement adapted to a further development of the general scheme.

Figure 9 illustrates means for indicating the condition of the track impedance by a method different than that employed in the preceding figures.

Figure 10 discloses the manner in which the signal transmission circuit may be superimposed upon the power supply circuit of an electric railway system.

Referring now to Figure 1,  $A_1$  represents the signaling station at what has been referred to as the sending end of the track circuit. The apparatus of this station may be located on the locomotive of a train as indicated in the figure.  $T$  represents the two rails of the track forming the two conductors of the electric circuit.  $A_2$  represents the "train ahead." At station  $A_1$  alternating current of high frequency is impressed through coil  $C$  upon the circuit represented by the rails of the track as bridged by the wheels and axle  $ax_1$  of the locomotive.  $B$  represents a Wheatstone bridge circuit for effecting a balance between the receiver  $R$ , and the generator  $G$ , and comprises the ratio arms  $a$  and  $b$ , the arm  $x$  corresponding to the branch of unknown impedance and the arm  $y$  corresponding to the rheostat arm of the ordinary Wheatstone bridge. The generator  $G$  may be any of the well known sources of high frequency alternating current such as the alternator, the Poulsen arc or the vacuum tube oscillator. The receiver  $R$  may be any type of instrument operative directly or indirectly from alternating current such as a hot wire or dynamometer type A. C. instrument or a D. C. instrument operated from a thermocouple or a rectifier. The track circuit is included, by means of coil  $C$ , in the  $x$  arm of the bridge circuit. The network  $N$  of arm  $y$  is adjusted to be equal in impedance at the frequency of the generator to the coil

$C$  together with its inductively related track circuit  $T$  (when there is no train on the track). There may be included in the arms  $x$  and  $y$  respectively balanced condensers  $c_1$  and  $c_2$  which tune these arms to the frequency employed, i. e., counteract the positive reactance, and thereby increase the sensitivity of the bridge circuit. The  $x$  and  $y$  arms are thereby made of equal impedances and balance the bridge circuit  $B$ .

The operation of the system is illustrated in Figure 1 as follows: Alternating currents generated at  $G$  pass equally through the ratio arms  $a-x$  and  $b-y$  of the bridge, cause no difference of potential across and therefore do not affect the receiver  $R$ . A part of the current in coil  $C$  is induced into the rail circuit  $T$ . Assume that the bridge circuit is balanced for a clear condition of the track circuit, in which case the receiver  $R$  is not operated by generator  $G$  and indicates a clear condition of the track ahead. The current induced in the track circuit propagates to  $A_2$ , the train ahead, and is reflected back to train  $A_1$  by the short circuiting effect of one or more of the axles of train  $A_2$ . The design of the system is made such that when the separation of the trains is so great as to constitute a clear track condition, then the attenuation of the track circuit is so great that the wave reflected back is too weak to affect the receiving apparatus at station  $A_1$ . When, however, the separation between the trains is so short as to be dangerous the reflected wave is returned to station  $A_1$  with amplitude sufficient to operate the receiver  $R$ . The course of this reflected current is through coil  $C$  and arm  $x$  to the bridge circuit  $B$  and thence to the receiver  $R$ . The balanced bridge circuit serves thus to discriminate between the outgoing and the reflected current; it prevents the former from having any effect on the receiver but it permits the latter to enter the receiver and cause it to respond. It will be understood that other suitable discriminatory devices may be employed if desired.

Another and more direct way of expressing this operation is to say that the bridge circuit  $B$  becomes unbalanced and causes the generator  $G$  to operate the receiver  $R$ , when the train ahead is closer than a certain limiting distance. As the separation between trains is still further reduced, the unbalance of the bridge circuit becomes greater and the deflection of the indicating instrument correspondingly larger. It will be noted that as the unbalance becomes greater the transmission efficiency between the generator and receiver increases, this efficiency being nil when the balance is perfect, as will be readily understood. As illustrated, the indicator is marked in three steps, one indicating clear, another danger, and a third stop. It will be



understood that any method of indication and any type of signaling device may be used.

The manner in which current is induced from coil C into the track circuit is explained more fully in reference to Figure 2. The combination of coil C and the three-quarter loop formed by the rails, and the short circuiting axle *ax*, form a transformer, the primary of which is coil C and the secondary of which is the said three-quarter track and axle circuit. The E. M. F., *E*, is impressed upon the track as a transmission circuit, through this track-coil transformer. Considering as terminals the points on the track at which the E. M. F., *E*, is impressed, then the "characteristic" impedance  $Z_0$  looking along the track is defined by the

ratio  $\frac{E}{I}$ , where *I*, is the alternating current

entering the track circuit at the terminal points.

This impedance  $Z_0$  is determined solely by the linear constants of the circuit as previously explained, in accordance with the expression

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

and is the impedance which obtains at the sending end of the track circuit when there is no train ahead or when the train is so far ahead that the reflected wave is damped out. This impedance will be appreciated to be a vector quantity having both magnitude and phase angle and resolvable therefore into a resistance and a reactance component  $Z_0 = R_0 + jX_0$ . This resistance component of course is not the same as the ordinary ohmic resistance of the circuit. In the case illustrated, where the frequency is high, its magnitude is determined more largely by the ratio of the inductance to the capacity of the circuit than by the ohmic resistance.

This "characteristic" impedance  $Z_0$  represents, then, the ratio of voltage to current intensity obtaining in the energy wave which is launched into the circuit and is determined solely by the linear constants of the circuit and not by the termination, whether open or short-circuited. When there is a train present on the track causing a short circuit, or when the track circuit is open as at a broken rail, then a reflected wave is set up at that point and this reflected wave upon return to the sending end is superimposed upon the then incident wave and changes the entrant impedance of the track circuit from that of the "characteristic" impedance to a resultant impedance. If the point of reflection is so far ahead as not to constitute danger, then the reflected wave is so highly attenuated as not to appreciably affect the sending end impedance and the

"characteristic" impedance obtains. If, however, the point of reflection, such as a train ahead, is nearby, then the resultant impedance as affected by the reflected wave is materially different from the characteristic impedance, and causes the actuation of the receiving device in a way which will be subsequently explained.

The manner in which the resultant entrant impedance is affected by the reflected wave as the distance out to the point of reflection is changed, is shown in graphical form in Fig. 3. This figure contains two curves, one the resistance component and the other the reactance component of the resultant entrant impedance (looking into the track circuit from the sending end). These two components combined represent the entrant impedance, which is a vector quantity, the magnitude and phase of which progressively change as the distance of the point of reflection changes, because of the progressive change in magnitude and phase of the returned wave. In other words, this impedance represents the ratio of a resultant electromotive force to a resultant current (in the track circuit and not in the receiver circuit itself).

The resistance component *R* of the entrant impedance ( $Z = R + jX$ ) represents the ratio of those components of the resultant voltage and current waves which are in phase. The reactance component *X* represents the ratio of those components of the voltage and current waves which are 90° out of phase. *j* denotes this 90° phase relation in accordance with the convention of complex algebra. Inasmuch as each of these is the resolved component of factors which are themselves the resultant of the outgoing and returned wave action, each may be expected to change in magnitude as the distance to the point of reflection is changed. This fact is apparent from the curves of the figure. When the short circuit is as far out as 10 miles, for example, the effect of the reflected wave is suppressed and the impedance is merely the characteristic impedance of about 400 ohms, without any reactance (for the case illustrated) as shown by the curve *R*. As the distance is decreased the reflected wave, as the strength with which it is received increases, gradually modifies the impedance. Both the resistance and the reactance curves are caused to deviate from true characteristic impedance, more and more as the distance is decreased. It will be noted that when the resistance component is a maximum or a minimum, the reactance component is zero and that when the reactance is a maximum or minimum, the resistance component is that of the characteristic resistance (about 400 ohms). This alternation of the two components is caused by the progressive change in the phase between the out-

going and the returned waves as the distance is decreased, and the increase in the magnitude of the excursions is caused by the increase in the strength of the returned wave as the distance is decreased. It is this control over the entrant impedance of the track circuit in accordance with the distance of the train ahead which is employed to effect the signalling on the locomotive behind. This is accomplished by providing a balanced circuit on the locomotive which balances the receiver against the transmitter for the condition of characteristic impedance, so that when this condition obtains, as it does when the tracks are clear for a considerable distance ahead, the circuit is balanced. Then for the condition where the track immediately ahead is occupied, the entrant impedance in the track circuit is materially altered and the circuit is unbalanced, thus giving the control signal.

The above explains the operation of the invention in terms of impedance and balanced circuits. While this is a convenient method of dealing with the subject, it should be remembered that impedances are simply numerics representing the ratio of voltage to current waves and that the actual entities involved in the operation of the system are the wave transmissions themselves. An energy wave stream is continuously propagated out along the track of the locomotive and, when the track ahead is clear, this energy transmission passes out in effect never to return. When, however, the track ahead is occupied or a rail is broken, then the energy stream is reflected and partially returned to the sending end and enters the receiving device independently of the outgoing stream upon which it is superimposed in the track circuit, and effects the control of the locomotive. It will thus be appreciated that the essential positive fact of the invention resides in the establishment of the transmission of energy out and back, and that the impedance diagram in Fig. 3 is simply a convenient way of showing the result of this out and back transmission in such terms as to link up with the wave propagation viewpoint the balanced circuit method of treatment.

In accordance with one method of operating this signal system, the bridge circuit of Figure 1 is balanced for the normal "clear track" impedance condition. As the impedance deviates from the normal with decreased train separation as illustrated in Figure 3, the unbalance between the source G and the receiver R of Figure 1 increases until the receiver is actuated and effects the desired signal. The exact point on the impedance curve of Figure 3, corresponding to a certain separation, at which the signal operates is determined by the ratio of the receiver sensitivity to the generator

power and may be adjusted for any desired value. The indicating instrument may be calibrated in terms of "clear" for normal impedance "caution" for a deflection of the receiver corresponding to the impedance change caused by the separation being reduced down to say 2 or 3 miles, and "danger" corresponding to a larger deflection caused by the larger impedance variation incident to the separation being reduced to say one mile. This ability to thus definitely relate the indication in the locomotive cab with the distance ahead of another train is an important part of the present invention.

One of the problems involved in the successful operation of this type of signal system is that of making suitable connection between the track and the local circuit on the locomotive. The means of Figures 1 and 2 for so doing operate on the principle of electromagnetic induction. The E. M. F., is induced in part directly in the rails and in part in the foremost axle of the locomotive. Other embodiments of electromagnetic inductors are shown in Figures 4 and 5.

In Figure 4 the inducing coil C is so designed and disposed in relation to the track circuit as to impress the E. M. F. directly upon the rails alone. Coil C is divided into two sub-coils, 1 and 2, for the two rails respectively. These coils are wound about a U-shaped core, which may be air or otherwise suitably laminated iron, and the cores are so disposed as to have a maximum inducing effect upon the rail in a well known manner as indicated. The inducing coil may be related solely with the axle as indicated in Figure 5. This is a less desirable disposition, however, because of the shunting effect of the trucks behind. It will be understood that any such track connecting means as described above may be located to the rear of one or more axles of the locomotive or train, in which case it is necessary to insulate the preceding axles and thereby prevent them from short circuiting the track and shielding the terminal circuit from changes in the condition of the track impedance. The connection with the track may be made through a pair of plates, one placed close to each rail and forming a condenser therewith, the other surface of the condenser being the rail itself, and the dielectric of the condenser being the air space between the plate and the rail. The vehicle circuit is thus associated with the track circuit by electrostatic rather than by electromagnetic induction. The track connection may also be made conductively by brushes bearing upon the rails, wheels or axles or by contact through the journals as illustrated diagrammatically in Figure 5<sup>a</sup>. The difficulties involved in making connection with the track inductively, through either mutual inductance or capacity, is in secur-

able changes in the track impedance to be detected in the local circuit of the locomotive. The use of relatively high frequencies is a feature of the invention in this respect in that it facilitates the transfer of energy across what is a transformer of relatively large magnetic leakage.

Figure 6 illustrates a terminal circuit arrangement broadly similar to that of Figure 1, but differing in respect to the bridge circuit design, the source of the high frequency alternating current, and the receiving mechanism. The bridge circuit B of Figure 1 is replaced by one of a different form involving a three winding transformer, 5, of a type well known in telephone engineering and commonly termed a hybrid coil. The source of current is connected to the mid points of the two windings forming the bridge circuit proper. The source is in this case a vacuum tube oscillator of form well known in communication engineering, and consisting of the three element audion or vacuum tube 15 with an input circuit comprising inductance 12 and condenser 14, and output circuit including inductance 13 coupled magnetically with inductance 12. This forms a so-called feed-back oscillating circuit, the period of oscillation of which is determined by the inductance 12 and capacity 14, and which can be changed by varying condenser 14, for instance. The high frequency alternating current so generated is taken off through a secondary coil 113 which, together with the other two coils 12 and 13, forms a transformer 11. The detecting branch of the bridge circuit is related with the bridge through the third winding of the transformer 5. This circuit is tuned by inductance 6 and capacity 7 to the frequency of the local source. The sensitivity of the entire circuit to variations in impedance through the coil C is increased by means of an amplifier 8 of the well known vacuum tube form. The indicating instrument 9 may be of the dynamometer type, similar to a wattmeter. It may be operated in either of two ways—either the two coils are connected in series, as in common practice, and excited from the output of amplifier 8, or one coil is excited from the oscillator, as shown, through circuit 10. In this latter case, the indication of the instrument becomes a function of the phase displacement of the return transmission. Selectivity is also imparted by the tuning of the detector branch referred to above, and by the tuning of the  $x$  and  $y$  arms of the bridge circuit proper.

In the embodiments described above the signal is given merely as a deflection of an indicating instrument. Such signal indicating means may be supplemented or replaced by relay devices set to operate at definite im-

pedance unbalances and to actuate signal alarm or control mechanism.

Figure 7 illustrates the use of relays actuated by a detecting device for operating alarm and control circuits. The left hand portion of the circuit, coil 5 in particular, is intended to fit with the detector branch of the bridge circuit of Figure 6. The received currents are tuned by inductance 6' and condenser 7', are amplified by the vacuum tube amplifier 8, are rectified by the vacuum tube detector 17, in the output circuit of which are the relays 18, 19 and 20. Relay 18 is the most sensitive and is adjusted to operate on a relatively small current corresponding to the moderate impedance irregularity caused by a train ahead coming within the caution zone. Its operation closes the circuit 21 and rings the alarm bell 22, or performs some other signaling operation. Relay 19 is given a marginal adjustment whereby it will respond to a current of some greater value corresponding to a nearer approach of the train ahead into the danger zone for instance, and closes the circuit 23 of an electro-magnetic device 24. The armature 25 is drawn in part way and effects a reduction in the speed of the train, as by partial operation of a steam valve and associated air brake valve 26. Upon the further approach of the train to the danger point, the detector current is further increased, relay 20, set to operate on this larger current, is actuated, circuit 27 is closed and the armature 25 is drawn in further and the steam and air valves are completely operated thus bringing the train to a stop.

Referring back to the impedance curves of Figure 3, it will be seen that within the distance at which the impedance irregularity becomes apparent, the resistance and reactance curves oscillate back and forth across the impedance value corresponding to a clear track. These curves oscillate with an approximately 90° phase displacement however, so that at no point within the range in which they oscillate, i. e., within say 6 miles, does their combined value equal the normal entrant impedance of the transmission circuit (the track). To further insure against the possibility of a false "safe" signal being given within the danger zone two currents of different frequencies may be employed simultaneously, and the giving of a "safe" signal made dependent upon their being affected similarly. Means for doing this are illustrated in Figure 8, which is generally similar to Figure 6.  $G_1$  and  $G_2$  are the two sources of high frequency alternating current, which sources are tuned by inductance-capacity combinations 30 and 31 respectively. The  $x$  and  $y$  arms are tuned for two different frequencies by the addition of tuning circuits 33 and 34 re-

spectively. The constants of circuits 33, for instance, are so adjusted with respect to those of condenser 1 and coil C as to give zero total reactance at the two frequen-

5 cies employed.  
The detector circuit is likewise resonated to two frequencies, by means of the tuned circuit 23 in combination with tuning elements 6 and 7. The amplifier 8 then ampli-  
10 fies currents of both frequencies in common, and either of these currents will operate the indicating circuit such as that of Figure 7. For all distances within the zone of operation of the signaling system the terminal circuit will be unbalanced to both of  
15 the two frequencies thus insuring operation.

The circuits described above are of a balanced type and operate by virtue of the effect upon the condition of balance of changes in the track impedance. The operation is described as one wherein the circuit is balanced for a clear track and unbalanced for an obstructed track. This adjustment may be reversed, i. e., the circuit may be normally unbalanced and the responding instruments normally actuated for the clear track condition, the balance being improved as the separation between  
20 trains is decreased, the improvement becoming such when the separation has reached a certain minimum as to release, say the alarm relay, and sound an alarm, and the balance being further improved with a further reduction in separation, resulting in the release of control relays and finally in the stoppage of the engine in the some general manner as described above.  
25 This method of operation corresponds to the closed circuit method of control employed in signaling circuits generally, while the reverse method first described above corresponds to the open circuit arrangement of ordinary signaling circuits. This closed  
30 circuit operation is illustrated as applied to another embodiment of the invention following.

Figure 9 illustrates a circuit arrangement operating on a principle different from that of the balanced types of circuits described above. The method of operation is that of causing the changes in the track impedance to effect changes in the period of oscillation of an oscillating circuit and to cause in turn the resulting changes in the frequency to control the receiving or indicating devices. The oscillating circuit is of a type well known in radio engineering. The vacuum tube amplifier 15' is connected on its input side across one-half of a coil C and on its output side with the second half of said coil as illustrated. A condenser 14' is bridged across the circuit and functions to determine in combination with the inductance of coil C, the period of oscillation.

The coil of the oscillator is related to the track circuit inductively and in this case is the coupling coil itself. Current generated by the oscillator is transmitted through transformer 40 across anti-resonant circuit  
70 41—42 to the amplifier 8' and thence to the detecting and indicating apparatus which may be generally similar to that of Figure 7.

The operation of the circuit arrangement is as follows: For the impedance value corresponding to clear track conditions, the oscillator generates a current of definite frequency. This current is passed through transformer 40 and amplifier 8' and normally holds in operation for instance, the relay responding devices. The circuit bridged across the input of the amplifier 8' is an anti-resonant circuit, comprising inductance 41 and condenser 42 tuned to and therefore offering a maximum impedance at the frequency normally generated by the oscillator and does not materially depreciate the transmission. A change in the track impedance causes a corresponding change in the constants of the coil C which shifts the frequency generated. For this changed frequency the anti-resonant circuit 41—42 offers a much lower impedance and effects a marked reduction in the current supplied to the detector 17' and associated responding devices 18' and 19'. These devices are so adjusted as to release at certain predetermined reductions in the current, so that they are actuated in accordance with the change in frequency suffered by the oscillator. The release of relay 19', for instance, releases relay 44 which trips off an indicating or control element 45. The method of operation here described is that of the closed circuit type. The open circuit type of operation is of course equally applicable.

Figure 10 illustrates the manner in which an alternating current railway signaling circuit may be superimposed upon the power supply circuit for an electric railway. While this arrangement is applicable to railway signaling systems generally it is especially useful in the reflected wave type of system because the power supply circuit is a more efficient and constant signaling transmission circuit than is the track circuit, described above in relation to Figure 2. Referring to Figure 10, 51 and 52 represent the two rails of the track which are, of course, well grounded to form the ground-return of the power supply circuit. The third rail, trolley or other power supply conductor is indicated as 53 while 54 is the shoe, pantagraph or other sliding contact member. The power receiving circuit is through the path from shoe 54, 55 through an inserted filter 56, the controller 57, the motor or motors M and back to ground  
130

through point 58 and the wheels and track. This power circuit may be D. C. or low frequency A. C. The filter 56 is provided for excluding the higher frequency signaling currents from the power receiving terminals 55, 57, M, 58. It consists of a plurality of sections of series inductance and shunt capacity and where the signaling and power frequencies are greatly different may be reduced to a simple inductance coil.

The signaling terminal circuit connecting with  $x$  corresponding with the circuit  $x$  of the previous figures, is bridged across the terminals 55 and 58 of the power receiving circuit through a filter 59. This filter functions to exclude the low frequency or D. C. power currents while passing the higher frequency signaling currents. It may take the form illustrated of a filter which transmits freely frequencies above an assigned limit, such as 100 cycles per second and which substantially excludes frequencies below this limit. In one well-known form this filter consists of a plurality of sections of series condensers and shunt coils. When the power and signaling frequencies are sufficiently different it may be simplified to a mere single series-connected condenser.

In thus applying the signaling circuit to the power supply system, the filter 56 or its equivalent may be provided in all shoe-connecting circuits of a train for the purpose of improving the signaling transmission efficiency of the power circuit. This provision in itself would tend to prevent the power terminal on the train ahead, for instance, from short circuiting or otherwise affecting the impedance of the third rail circuit sufficiently for signaling by the reflected wave principle. It is therefore desirable to either omit the filter 56 from one or more of the shoe-circuits not employed in the signaling circuit, or to add the filter 59 of the signal branch circuit and to short-circuit the signal terminal circuit  $x$  thereby to short circuit the third rail at the signaling frequency and at a point considerably behind the signaling generator and receiver. Another way of insuring that a train will materially affect the third rail circuit impedance is to purposely not fit together the impedances of the terminal and of the transmission third rail circuit. Still another way of so doing is to operate successive trains on different signaling frequencies and to provide an anti-resonant circuit, 60, across the signaling terminal circuit. This is tuned to the frequency employed aboard its train and has no appreciable effect upon the home signaling system. It does however act as a considerable shunt and therefore causes reflection at all other frequencies such as that employed by the train behind. Expressed more broadly this constitutes a means whereby each train may be made to substantially

short circuit the transmission circuit with respect to all other trains while selectively opening this short for itself thus enabling it to get in on the circuit without material sacrifice in transmission efficiency.

It will be understood that the invention permits of many variations and permutations in the manner of practicing it without departing from the scope and spirit thereof as defined in the following claims.

What I claim is:

1. The method of railway signaling which consists in altering the impedance of a transmission circuit comprising both track rails in accordance with the length of track between a train and a source of danger producing corresponding changes in the balance of a circuit and operating thereby a signal device.

2. The method of railway signaling by the reflected wave principle which consists in impressing upon the transmission circuit a frequency sufficiently high as to attenuate and substantially suppress the effect of the reflected wave for distances greater than that to which it is desired that the receiver be responsive.

3. In a railway signaling system the combination of a source of alternating current, a receiver therefor and means whereby the effect of said source upon said receiver is determined by the entrant impedance condition of the track.

4. In a railway signaling system, the combination of a source of alternating current, a vacuum tube type of receiver, balanced discriminating means included between said source and said receiver and means whereby the effect of said source upon said receiver is determined in accordance with traffic conditions.

5. In a railway signaling system, the combination of a source of alternating current, a vacuum tube type of receiver, high frequency discriminating means included between said source and said receiver and means for controlling the effect of said source upon said receiver in accordance with the position of a vehicle.

6. In a railway signal or control system, a source of alternating current, a receiver therefor comprising an amplifier, a vacuum tube detector and a relay, said source and relay being at the same location and means continuously responsive to traffic conditions whereby the operation of said relay is continuously controlled by said source of alternating current in accordance with said conditions.

7. In a railway signal or control system, a source of alternating current, a vacuum tube detector therefor adjacent said source, a plurality of relays, said source and relays being at the same location; and means continuously responsive to traffic conditions for

continuously governing the operation of said relays by said source in accordance with said conditions.

8. In a railway signaling system, a transmission circuit extending along the right of way, said circuit being controlled by traffic conditions so as to change its impedance progressively in accordance with the distance from a source of danger, a source of high frequency alternating current for said circuit, a signal device, said device comprising a vacuum tube, means for so associating said circuit, source and device, that said device is non-responsive to said source, and means for rendering said device responsive to said source under certain predetermined impedance conditions of said circuit.

9. In a railway signaling system, a circuit responsive to traffic, a source of current therefor, a device for balancing said circuit, said device having an impedance equal to that of the said circuit for certain traffic conditions, so that the balance between the said circuit and device is upset for either an open or a short-circuit condition of said circuit, a signal translating device and means responsive to an unbalance between said circuit and balancing device to cause an operation of said signal device.

10. A railway signaling system comprising a circuit responsive to traffic conditions, the impedance of said circuit being subject to change progressively in accordance with the distance from a source of danger, a source of high frequency current therefor, a device responsive to direct current, and means comprising a vacuum tube rectifier whereby said device is so associated with said circuit as to be responsive to the high frequency current therein.

11. A railway signaling system comprising a circuit responsive to traffic conditions, the impedance of said circuit being subject to change progressively in accordance with the distance from a source of danger, a vacuum tube oscillator associated with said circuit for impressing thereon current of predetermined frequency, a device responsive to direct current and means for associating said device with said circuit and rendering the same selectively responsive to current from said oscillator, said means comprising a frequency-selective device, and means for rectifying said current.

12. A railway signalling system comprising a signal circuit including a signaling device, a traffic controlled means, a source of alternating current energy comprising means whereby energy is sent from the location of the signal into said traffic controlled means, said traffic controlled means having the property of sending electric energy back to said signal location under certain traffic conditions so as to enter said signal circuit and effect an indication of the signal, and means

for preventing the outgoing energy from passing directly from the said source into the signal circuit without passing through the traffic controlled means.

13. The system as in claim 12, in which the said signal circuit and the said source are located on a railway vehicle, and in which inductive means are provided for effecting the transfer of energy to and from the traffic controlled means.

14. The combination claimed in claim 12, in which said traffic controlled means comprises a circuit extending along the right of way for carrying both the outgoing and returning energy transmissions.

15. The system as described in claim 12, in combination with means whereby the return wave is rendered ineffective to control the signal when the distance between the signal location and the point at which the return wave is originated exceeds a minimum desired for safety.

16. The system as described in claim 12, in which said alternating current circuit in the right of way comprises the rails of the track.

17. The system as described in claim 12, in which said signal device is located on the train and in which the said alternating current circuit extends ahead of the train.

18. A railway traffic control system comprising a signal device located on a railway vehicle, an alternating current transmission path, said path comprising the rails of the track ahead of the vehicle, means whereby electric energy is sent out from the vehicle through said transmission path, and means whereby certain traffic conditions cause an electric irregularity in the said path, said irregularity causing the reflection of energy along said path toward said signal to effect a certain indication thereof.

19. The system as described in claim 18, in combination with means whereby the irregularity is introduced into the track rail transmission path by the short circuiting of the said path as by the wheels and axles of a preceding car or train, or by the opening of the said path, as by a broken rail.

20. The system as described in claim 12, in combination with a balanced circuit arrangement for associating the signal with the said alternating current circuit, whereby the effect on the signal of the outgoing wave is neutralized but not the effect thereon of the returning wave.

21. A system for controlling railway traffic, comprising a signal device, a transmission path in the right of way, a circuit arrangement, comprising a circuit for balancing the said path, and for associating the signal device with the said path, and means whereby electric energy is sent from the location of the signal through said path, said balancing circuit having an impedance equal to the characteristic impedance of the

said path, so that either an opening or a short-circuiting of said path will bring about an unbalance and a control of the signal.

5 22. The system as described in claim 12, in which the electric wave energy impressed on the said circuit in the right of way comprises a plurality of waves differing in frequency.

10 23. In a railway signalling system, a source of energy, a receiving device, means for associating said source and device, said means including a balanced circuit arrangement for rendering said receiving device under normal traffic conditions non-respon-  
15 sive to said source, said balanced circuit arrangement including a wayside circuit whereby a change in the impedance of said circuit will upset the balance of said circuit arrangement and cause an actuation of the  
20 receiving device.

24. In a railway signalling system, a source of energy, a signalling device, a way-  
side circuit responsive to traffic conditions, and means for operatively associating said  
25 source, circuit, and signalling device, said means comprising an impedance arrangement for balancing the impedance of the wayside circuit under normal traffic condi-  
tions.

30 25. In a railway signalling system, a source of energy, a signalling device, a way-  
side circuit responsive to traffic conditions, and means for operatively associating said  
35 source, circuit, and signalling device, said means comprising an impedance device hav-  
ing an impedance equal to the characteristic impedance of said wayside circuit, whereby  
40 either an opening or a closing of said circuit will cause an unbalance of said circuit ar-  
rangement so as to bring about an actuation of said signal device.

26. In a railway signalling system, a source of high frequency alternating cur-  
rent, a signal device, said device comprising  
45 a vacuum tube, said source and device being located on a railway vehicle, and traffic controlled means for governing the response of said device to said source.

50 27. In a railway signalling system, a source of high frequency alternating cur-  
rent, said source comprising an electron

tube oscillator, a signal device, said device comprising an electron tube detector, said source and device being located on a railway vehicle, and traffic controlled means for gov-  
55 erning the response of said signal device to said source.

28. In a railway signalling system, a source of current and a signal, said source and signal being located on a railway ve-  
60 hicle, said source comprising a generator of high frequency alternating current, an elec-  
tron tube interposed between said source and said signal, and traffic controlled means for governing the response of said signal to cur-  
65 rent from said source.

29. In a railway signalling system, a source of current and a signal, said source and signal being located on a railway ve-  
70 hicle, said source comprising a generator of high frequency alternating current, an elec-  
tron tube interposed between said source and said signal, and traffic controlled means for governing the response of said signal to cur-  
75 rent from said source, said means comprising a wayside circuit.

30. In a railway signalling system, a source of current and a signal, said source and signal being located on a railway ve-  
80 hicle, said source comprising a vacuum tube oscillator for generating high frequency al-  
ternating current, an electron tube inter-  
posed between said source and said signal, and traffic controlled means for governing  
85 the response of said signal to current from said source, said means comprising a way-  
side circuit.

31. In a railway signalling system, a source of current and a signal, said source and signal being located on a railway ve-  
90 hicle, said source comprising a vacuum tube oscillator for generating high frequency al-  
ternating current, a detector and a vacuum tube amplifier, and traffic controlled means  
95 for governing the response of said signal to current from said source, said means comprising a wayside circuit.

In testimony whereof, I have signed my name to this specification this 19th day of November, 1919.

LLOYD ESPENSCHIED.