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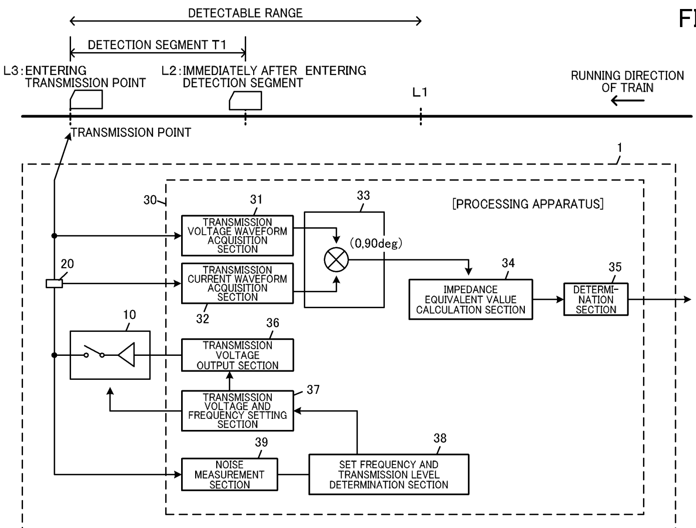
(54) TRACK CIRCUIT DEVICE AND TRAIN ON-TRACK DETERMINATION METHOD

(57) A track circuit apparatus (1) measures a transmission voltage and transmission current of an AC signal transmitted to rails, calculates an impedance equivalent value based on amplitudes of and a phase difference between the measured transmission voltage and transmission current, and determines presence of the train based on values of real and imaginary component values of the calculated impedance equivalent value.

FIG.1



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Description

[TECHNICAL FIELD]

[0001] The present disclosure relates to a track circuit apparatus and others.

[BACKGROUND ART]

[0002] In conventional track circuit apparatuses, a transmitter that transmits a train detection signal is connected to one end of a rail of a track circuit, and it is determined that a train is present on the rail, based on a lowered reception level at a receiver connected to the other end (e.g., see Patent Document 1).

[RELATED-ART DOCUMENT]

[PATENT DOCUMENT]

[0003] Patent Document 1: Japanese Unexamined Patent Application Publication No. 2021-113023

[SUMMARY OF THE INVENTION]

[TECHNICAL PROBLEM]

[0004] Conventional track circuit apparatuses require transmission power at or above a certain level because the apparatuses transmit a train detection signal to one end of a rail of a track circuit and monitor a reception level at the other end thereof which is a predetermined distance apart. As a result, it may be difficult to save energy. In addition, conventional track circuit apparatuses, in principle, require a transmitter and a receiver.

[0005] A problem to be addressed by the present disclosure is to provide a technology for track circuit apparatuses which is quite different in principle from that for conventional track circuit apparatuses.

[SOLUTION TO PROBLEM]

[0006] A first aspect to accomplish the foregoing object is a track circuit apparatus that includes: a calculation section that calculates an impedance equivalent value, based on amplitudes of a transmission voltage and a transmission current of an alternating current signal transmitted from a transmission section to a rail and a phase difference between the transmission voltage and the transmission current; and a determination section that determines presence of a train on the rail, based on values of a real component and an imaginary component of the impedance equivalent value.

[0007] Another aspect may configure an on-rail train presence determination method comprising measuring a transmission voltage and a transmission current of an alternating current signal transmitted from a transmission section to a rail; calculating an impedance equivalent value, based on amplitudes of the transmission voltage and the transmission current and a phase difference between the transmission voltage and the transmission current; and determining presence of a train on the rail, based on values of the real component and the imaginary component of the impedance equivalent value.

[0008] As a result, in the first aspect and others, it is possible to realize a technology for track circuit apparatuses which is quite different in principle from that for conventional track circuit apparatuses. The first aspect and others are a technique that focuses on the feature in which the impedance of the track circuit as viewed from the transmission point of the AC signal changes depending on whether a train is present or absent on the rail. With this impedance change, the amplitudes of and phase difference between the transmission voltage and the transmission current are varied. As a result, in the first aspect and others, the impedance equivalent value of the track circuit is determined from the amplitudes of and phase difference between the transmission voltage and the transmission current. Then, the presence of a train on the rail is determined based on the real component (resistance component) and imaginary component (reactance component), both of which express the impedance equivalent value with complex numbers. Since the presence of a train on the rail can be determined based on the transmission voltage and transmission current of the AC signal transmitted to the rail, no receiver is necessary, and there is no need to transmit a signal with a constant signal level at the reception point, thereby successfully reducing the transmission power. Consequently, it is possible to realize an energy-saving track circuit apparatus. Moreover, since no receiver is necessary, it is possible to provide a further effect in which the number of components constituting the track circuit apparatus can be made smaller.

[0009] A second aspect is the track circuit apparatus in the above-described aspect, in which the determination section determines a location of the train present on the rail relative to a transmission point of the alternating current signal from the transmission section.

[0010] As a result, in the second aspect, it is possible to determine the location of the train present on the rail relative to the transmission point of the AC signal. This is because the impedance of the track circuit as viewed from the transmission point of the AC signal changes depending on a location at which the rail is shorted by the axle of the train.

[0011] A third aspect is the track circuit apparatus in the above-described aspects, in which the determination section determines the location of the train present on the rail relative to the transmission point, based on a plot point of the impedance equivalent value in a coordinate system with axes representing the real component and the imaginary component.

[0012] As a result, in the third aspect, the determination section can determine the location of the train present on the rail, based on the plot point of the impedance equivalent value in the coordinate system (complex plane) with axes representing the real component and the imaginary component. This is because the impedance of the track circuit depends on a location at which the rail is shorted by the axle of the train. Therefore, by relating in advance locations of a train present on the rail with the plot points of the impedance equivalent values in the coordinate system, it can be determined that the location of the train present on the rail.

[0013] A fourth aspect is the track circuit apparatus in the above-described aspects, in which the determination section determines the location of the train present on the rail, based on a location of the plot point along a predetermined reference trajectory in the coordinate system.

[0014] The impedance of the track circuit depends on the location of the train present on the rail in the track circuit, namely, the location at which the rail is shorted by the axle of the train. Therefore, by defining in advance, as a reference trajectory, the change in the location of the plot point of an impedance equivalent value in the coordinate system that is related to the location of the train on the rail, as in the fourth aspect, it can be determined that the location of the train on the rail, based on the location of plot point along this reference trajectory.

[0015] A fifth aspect is the track circuit apparatus in the above-described aspects, in which the determination section determines a state of the rail, based on the values of the real component and the imaginary component of the impedance equivalent value.

[0016] The impedance of the track circuit changes in response to a change in the state of the rail. Thus, by comparing the values of the real component and imaginary component of a current impedance equivalent value with the real component and imaginary component of the impedance equivalent value when the rail is in a normal state, for example, as in the fifth aspect, it can be determined that the state of the rail, such as whether the rail is in a normal state.

[0017] A sixth aspect is the track circuit apparatus in the above-described aspects, in which the determination section determines a location of an abnormality on the rail relative to the transmission point of the alternating current signal from the transmission section.

[0018] As a result, in the sixth aspect, it is possible to determine, as the state of the rail, the location of an abnormality on the rail relative to the transmission point of the AC signal.

[0019] A seventh aspect is the track circuit apparatus in the above-described aspects, in which, when the plot point deviates from the reference trajectory, the determination section determines the location of an abnormality related to leakage conductance and/or a rail breakage on the rail, based on the deviating location.

[0020] As a result, in the seventh aspect, it is possible to determine, as the state of the rail, the location of the abnormality related to leakage conductance and/or a rail breakage on the rail. For example, if an abnormality related to leakage conductance, such as an increase in leakage conductance due to submersion of the rail, occurs in the rail, the amount of change in the impedance of the track circuit varies depending on the location of the train present on the rail before and after the train passes through the abnormality location. Therefore, when a plot point deviates from the reference trajectory, it can be determined that the location at which a plot point returns to the reference trajectory is the location at which the abnormality related to the leakage conductance has occurred on the rail. More specifically, when the train passes in front of and in back of the location of an abnormality related to leakage conductance, the plot points deviate from the starting point of the reference trajectory (moves toward the transmission point) in front of the abnormal location and draw a trajectory conforming to the reference trajectory after the train has passed through the abnormal location. Even if a rail breakage occurs, the amount of change in the impedance of the track circuit varies before and after the train passes the location of this abnormality. Therefore, when a plot point deviates from the reference trajectory, it can be determined that the location at which a plot point returns to the reference trajectory is the location of the rail breakage. More specifically, when a train passes in front of and in back of the location of a rail breakage, the portion of the rail other than the location of the abnormality is normal. However, the portion beyond the abnormal location deviates from the reference trajectory, so that the plot points are each displaced between a location along the reference trajectory and a location deviating from the reference trajectory.

[0021] An eighth aspect is the track circuit apparatus in the above-described aspects, in which the determination section determines whether a rail breakage has occurred, based on a sign of a value of the imaginary component.

[0022] As a result, in the eighth aspect, it can be determined whether a rail breakage has occurred, based on the sign of the value of the imaginary component of the impedance equivalent value. This is because, when a rail breakage occurs, the imaginary component of the impedance equivalent value has a negative value.

[0023] A ninth aspect is the track circuit apparatus in the above-described aspects, in which the determination section determines a location of the rail breakage relative to the transmission point of the alternating current signal from the transmission section, based on the values of the real component and the imaginary component of the impedance equivalent value.

[0024] As a result, in the ninth aspect, it is possible to determine the location of the rail breakage relative to the transmission point of the AC signal, based on the values of the real component and the imaginary component of the impedance equivalent value. This is because, when a rail breakage occurs, the imaginary component of the impedance equivalent value has a negative value, and each of the real component and imaginary component is changed to a value proportional to the distance from the transmission point of the AC signal to the location of the rail breakage.

[0025] A tenth aspect is the track circuit apparatus in the above-described aspects, in which the determination section determines an abnormality of the rail or an indication of the abnormality, based on whether a plot point of the impedance equivalent value in a coordinate system with axes representing the real component and the imaginary component is outside a tolerance fluctuation range of the impedance equivalent value, the tolerance fluctuation range being defined in accordance with a distance from the transmission point of the alternating current signal from the transmission section.

[0026] If some abnormality occurs or an indication of the abnormality appears on the rail, the impedance of the track circuit changes. In addition, since rails are usually installed outdoors, the impedance of the track circuit may fluctuate due to ambient environment, such as temperature, humidity, rainfall, or snowfall. As a result, a tolerance fluctuation range by which the state of the rail can be regarded as being normal is defined in advance with reference to a preset location of the plot point of the impedance equivalent value when the rail is in a normal state, for example, as in the tenth aspect. It is thereby possible to determine an abnormality on the rail or an indication of the abnormality, based on whether the plot point of the impedance equivalent value is outside the tolerance fluctuation range.

[BRIEF DESCRIPTION OF DRAWINGS]

[0027]

FIG. 1 is a diagram of an application example of a track circuit apparatus.
FIG. 2A is a diagram of an equivalent circuit of a track circuit.
FIG. 2B is a diagram of an equivalent circuit of the track circuit.
FIG. 2C is a diagram of an equivalent circuit of the track circuit.
FIG. 3 illustrates an example of a transmission voltage waveform and transmission current waveforms of an AC signal.
FIG. 4 illustrates an example of the change in a plot point of an impedance equivalent value.
FIG. 5 illustrates an example of the change in the plot point of the impedance equivalent value in the case of a rail breakage.
FIG. 6 illustrates an example of the change in the plot point of the impedance equivalent value in the case of a rail breakage.
FIG. 7 illustrates an example of the change in the plot point of the impedance equivalent value in the case of an abnormality related to leakage conductance.
FIG. 8 illustrates an example of the installation of track circuit apparatuses.
FIG. 9 illustrates an example of how to set a tolerance fluctuation range.
FIG. 10 illustrates another configuration example of a track circuit apparatus.
FIG. 11 illustrates an example of the change in the plot point of the impedance equivalent value in the case of an insulated track circuit.

[DESCRIPTION OF EMBODIMENTS]

[0028] A preferred exemplary embodiment of the present disclosure will be described below with reference to the accompanying drawings. It should be noted that exemplary embodiments to which the present disclosure is applicable are not limited to the exemplary embodiments to be described below. In the drawings, the same elements are denoted by identical reference numerals.

[Configuration]

[0029] FIG. 1 illustrates an application example of a track circuit apparatus 1 according to the present embodiment. The track circuit apparatus 1 is an apparatus that transmits an alternating current (AC) signal to rails and then determines the presence of a train on the rails as well as a state of the rails, based on a transmission voltage and transmission current of the AC signal. The track circuit apparatus 1 includes a transmitter 10, a current sensor 20, and a processing apparatus 30. If a plurality of track circuit apparatuses 1 are installed centrally in one location, some long cables are necessary, in which case matching transformers are also provided to match the impedances of the cables and the track to some extent.

[0030] The transmitter 10 transmits a certain level of AC signal via a transmission cable to a transmission point in a detection segment T1, which is defined by separating the rails of a track circuit, under the control of the processing apparatus 30. The transmitter 10 may correspond to an example of a transmission section. The transmission point is provided on the exit side of the detection segment T1. The track circuit may be either an uninsulated or insulated track circuit; however, the present embodiment will be described on the assumption that the track circuit is an uninsulated track circuit. Thus, when being transmitted to the rails in detection segment T1 via the transmission point, the AC signal also propagates to another section adjacent to the detection segment T1. The current sensor 20 is installed in a transmission cable between the transmitter 10 and one rail and measures the current (the alternating current) of the AC signal to be transmitted to the rail.

[0031] The processing apparatus 30 includes a transmission voltage waveform acquisition section 31, a transmission current waveform acquisition section 32, a quadrature detection circuit section 33, an impedance equivalent value calculation section 34, a determination section 35, a transmission voltage output section 36, a transmission voltage and frequency setting section 37, a set frequency and transmission level determination section 38, and a noise measurement section 39. Each of the functional sections constituting the processing apparatus 30 can be formed of a circuit section that processes signals to realize the function thereof and/or a calculation processing section that realizes the function thereof by means of software.

[0032] The transmission voltage waveform acquisition section 31 acquires the waveform (transmission voltage waveform) of the transmission voltage of the AC signal to be transmitted to the rails in the detection segment T1 via the transmission cable. The transmission current waveform acquisition section 32 acquires the waveform (transmission current waveform) of the transmission current measured by the current sensor 20. The quadrature detection circuit section 33 performs quadrature detection of the transmission voltage waveform and the transmission current waveform and then outputs the amplitudes of the transmission voltage and the transmission current and the phase difference of the transmission current relative to the transmission voltage. The impedance equivalent value calculation section 34 calculates a real component and an imaginary component, based on the amplitudes of and phase difference between the transmission voltage and the transmission current output from the quadrature detection circuit section 33; each of the real component and the imaginary component expresses an impedance equivalent value of the track circuit with a complex number. The impedance equivalent value calculation section 34 may correspond to an example of a calculation section. Details of the impedance equivalent value of the track circuit will be described later.

[0033] The determination section 35 determines the presence of a train on the rails and a state of the rails, based on the values of the real component and imaginary component of the impedance equivalent value calculated by the impedance equivalent value calculation section 34. Details of how to determine the presence of a train on the rails and a state of the rails will be described later.

[0034] The transmission voltage output section 36 outputs, to the transmitter 10, the transmit voltage set by the transmission voltage and frequency setting section 37. The transmission voltage and frequency setting section 37 controls the transmission voltage of the transmission voltage output section 36 in such a way that the transmission level of the AC signal becomes equated with that determined by the set frequency and transmission level determination section 38. In addition, the transmission voltage and frequency setting section 37 controls the turn-on/turn-off of a transmission switch in the transmitter 10 in such a way that the set frequency of the AC signal becomes equated with that set by the set frequency and transmission level determination section 38. The set frequency and transmission level determination section 38 determines the frequency and transmission level of the AC signal to be transmitted to the rails, based on noise (return noise) measured by the noise measurement section 39. The noise measurement section 39 measures noise (return noise) generated on the rails of the track circuit. Details of how to measure the noise and set the frequency and level of the AC signal will be described later.

[On-rail train presence determination]

[0035] How to determine the presence of a train on the rails with the determination section 35. Each of FIGs. 2A, 2B, and 2C is a diagram illustrating an equivalent circuit when the detection segment T1 is regarded as the track circuit and illustrates the equivalent circuit depending on whether a train is present or absent on the rails and a location at which the train is present on the rails. FIG. 2A illustrates the equivalent circuit when no train is present on the rails. FIG. 2B illustrates the equivalent circuit immediately after the train has entered the detection segment T1 (at an on-rail location L2 in FIG. 1). FIG. 2C illustrates the equivalent circuit when the train enters (reaches) the transmission point (an on-rail location L3 in FIG. 1). It should be noted that the rail is in a normal state (no abnormality has occurred) in this case. The synthetic impedance of this equivalent circuit is equivalent to the impedance of the track circuit as viewed from the transmission point of the AC signal.

[0036] As illustrated in FIG. 2A, when no train is present on the rails, the equivalent circuit of the track circuit is formed of inductance components La and series resistance components Ra of the rails, capacitance components C between the rails, and leakage conductance components G (= 1/Rb). As illustrated in FIG. 2B, immediately after the train has entered the detection segment T1, the equivalent circuit of the track circuit is formed of the inductance components La and the series resistance components Ra of the rails in the detection segment T1, the capacitance components C between the rails, the leakage conductance components G (= 1/Rb), and an impedance Rv generated by the axle shorting.

[0037] In the present embodiment, the track circuit is an uninsulated track circuit. Thus, when being transmitted to the rails via the transmission point, the AC signal also propagates to another segment adjacent to the detection segment T1. In this case, even in a state where the train has not yet reached the detection segment T1, the axle-shorting impedance Rv is not negligible as long as the train is approaching a certain distance. After the train has exited the detection segment T1, the axle-shorting impedance Rv is not still negligible until the train moves a certain distance away. The range in which the axle-shorting impedance Rv is not negligible (the range that the AC signal reaches) is referred to as the detectable range. In short, the detectable range corresponds to a range defined by extending the detection segment T1 in the front-back directions along the rails. Furthermore, the individual circuit elements of the track circuit (the inductance components La and the series resistance components Ra of the rails, the capacitance components C between the rails, and leakage conductance components G (= 1/Rb)) each depend on the distance from the transmission point of the AC signal to the axle-shorting location (the location of the train present on the rails). More specifically, each circuit element is maximum when no train is present on the rails and then gradually decreases as the train is approaching the transmission point of the AC signal.

[0038] As illustrated in FIG. 2C, when the train enters the transmission point, the equivalent circuit of the track circuit is formed of the axle-shorting impedance Rv alone. In this case, since the distance from the transmission point to the axle-shorting location is very short, each of the inductance components La and the series resistance components Ra of the rails, and the capacitance components C between the rails has a very small value, but each leakage conductance component G (= 1/Rb) has a very large value. Consequently, the equivalent circuit of the track circuit changes with the running of the train in the detection segment T1. More specifically, the impedance of the track circuit changes.

[0039] FIG. 3 illustrates an overview of the transmission voltage waveform and transmission current waveforms of the AC signal to be transmitted to the rails. FIG. 3 illustrates a transmission voltage waveform and transmission current waveforms, with the horizontal axis representing the time and the vertical axis representing the level. In this case, the transmission voltage waveform is unchanged, and FIG. 3 illustrates the transmission current waveforms when no train is present on the rails and when the train enters the transmission point (on-rail train location L3).

[0040] As illustrated in FIGs. 2A, 2B, and 2C, the equivalent circuit of the track circuit in the detection segment T1 changes with the running of the train from the entry point of the detection segment T1 to the exit point thereof. In short, since the impedance of the track circuit as viewed from the transmission point of the AC signal changes, the transmission current waveform changes relative to the transmission voltage waveform. More specifically, as the train is approaching the transmission point after having entered the detection segment T1, the phase of the transmission current waveform is shifted in the opposite phase direction relative to the transmission voltage waveform, and the level (amplitude) of the transmission current waveform increases. In short, the amplitude (level) and phase of the transmission current waveform vary with the change in the impedance of the track circuit. From this, the amplitudes of the transmission voltage waveform and the transmission current waveform and the phase difference of the transmission current waveform relative to the transmission voltage waveform can be regarded as a value (impedance equivalent value) equivalent to the impedance of the track circuit.

[0041] In the present embodiment, the quadrature detection circuit section 33 performs the quadrature detection of the transmission voltage waveform and the transmission current waveform and then outputs the amplitudes of the transmission voltage waveform and the transmission current waveform and the phase difference therebetween. Based on the amplitudes and the phase difference, the impedance equivalent value calculation section 34 then calculates the real component and imaginary component, which express the impedance equivalent value of the track circuit with complex numbers.

[0042] FIG. 4 is a diagram illustrating a varying impedance equivalent value of the track circuit during the running of the train in the detection segment T1 . More specifically, FIG. 4 is a diagram illustrating the plot points of impedance equivalent values in the Cartesian coordinate system (complex plane), with the axes representing the real component and the imaginary component. Moreover, FIG. 4 illustrates variations (trajectory) in the plot points of the impedance equivalent values of the track circuit during the period in which the train is not present, then enters the detection segment T1, and exits therefrom.

[0043] As illustrated in FIGs. 2A, 2B, and 2C, the impedance equivalent value of the track circuit varies in an analog fashion with the change in the location of the train on the rails (i.e., the axle-shorting location on the rail). As a result, the variations in the locations of the plot points of the impedance equivalent value also draw a continuous trajectory. More specifically, when no train is present on the rails, both the real component and imaginary component of the impedance equivalent value of the track circuit have positive values, in which case the location P1 of the plot point is positioned within the first quadrant. The location P1 of the plot point is substantially fixed as long as the rail is in a normal state.

[0044] When the train enters the detectable range, the impedance of the track circuit changes with the change in the location of the train on the rails (i.e., the axle-shorting location on the rail). As a result, the location of the plot point of the impedance equivalent value gradually changes from the location P1. In short, as the distance between the transmission point of the AC signal and the axle-shorting location gradually shortens, the values of the real component and imaginary component of the impedance equivalent value gradually decrease. As a result, the location of the plot point of the impedance equivalent value changes in the direction toward (approaching) the origin O in the Cartesian coordinate system. A location P2 corresponds to the location of the plot point of the impedance equivalent value immediately after the train has entered the detection segment T1 (location L2 in FIG. 1).

[0045] Continuing the above, when the train enters the transmission point (on-rail location L3 in FIG. 1), the location of the plot point of the impedance equivalent value coincides with a location P3 near the origin O. After the train has exited from (passed through) the transmission point, the plot point of the impedance equivalent value changes in the order opposite to the previous one so as to gradually return to the location P1. Therefore, by detecting that the plot point starts to be displaced toward the location P1 after the plot point has been closest to the origin O (or the location very near the origin O), the track circuit apparatus 1 can determine that the train has exited from the transmission point. In this case, the track circuit apparatus 1 can determine in which direction relative to the transmission point the train is running, based on whether the plot point is displaced toward or away from the origin O.

[0046] As described above, the track circuit apparatus 1 can determine whether a train is present or absent on the rails in the detection segment T1, from the change in the plot point of the impedance equivalent value of the track circuit in the Cartesian coordinate system (complex plane) with the axes representing the real component and the imaginary component. When the plot point coincides with the location P1, the track circuit apparatus 1 determines that a train is not present (is absent) on the rails. When the plot point starts to change from the location P1 toward the origin O, the track circuit apparatus 1 determines that the train is approaching the detection segment T1. When the plot point coincides with the location P2, the track circuit apparatus 1 determines that the train has entered the detection segment T 1, namely, that the train is present on the rails. If the plot point is displaced from the location P2 to the location P3 (origin O) and then returns to the location P2 again, the track circuit apparatus 1 determines that the train has exited from the detection segment T1, namely, that no train is present on the rails. After that, when the plot point changes so as to return to the location P1, the track circuit apparatus 1 determines that the train that has exited from the detection segment T1 is moving away. When another train is newly approaching, the track circuit apparatus 1 can determine whether this train is present or absent on the rail in the same manner, based on the change in the location of the plot point of the impedance equivalent value from the location P1.

[0047] As described above, the track circuit in the present embodiment is an uninsulated track circuit. Thus, when being transmitted from the transmission point to the rail, the AC signal also propagates to an adjacent segment on the exit side (on the exit side in the running direction) of the detection segment T1. For this reason, the track circuit apparatus 1 may determine whether the train is present or absent on the rails, with the adjacent segment on the exit side being included in the detection segment T1. In this case, when the plot point of the impedance equivalent value is displaced to the location P3 (origin O) and then further displaced to a location corresponding to the distance to the adjacent segment, the track circuit apparatus 1 may determine that the train has exited from the detection segment T1 (no train is present).

[0048] The location of the plot point of the impedance equivalent value in the Cartesian coordinate system (complex plane) depends on the impedance of the track circuit, namely, the rail-shorting location (the location at which the train is present on the rails). Therefore, by determining in advance the relationship between locations of the train on the rails (rail-shorting location) and the locations of the plot points of the impedance equivalent values, for example, through measurement, the location of the train present on the rails can be determined, based on the location of the plot point relative to the transmission point of the AC signal.

[0049] The trajectory that represents the change in the plot point of the impedance equivalent value in this Cartesian coordinate system (complex plane) has a unique shape depending on the detection segment. Therefore, the trajectory along the impedance equivalent value follows with the running (passing) of the train can be determined in advance when the rails are in a normal (not in an abnormal) state. The trajectory along which the plot point of the impedance equivalent value follows when the rails are in a normal state is referred to as the reference trajectory.

[Determination of state of rails]

[0050] Next, how to determine a state of the rails with the determination section 35 will be described. The state of the rails is determined by comparing the plot point of the impedance equivalent value and the reference trajectory. The determination of the state of the rails corresponds to the determination of whether the rails are in a normal (abnormal) state. As an abnormal state of the rails, an abnormality related to a rail breakage or leakage conductance is determined.

(A) Rail breakage

[0051] FIG. 5 is a diagram illustrating an example of plot points of impedance equivalent values in the case of a rail breakage. FIG. 5 illustrates, together with the reference trajectory, the plot points of impedance equivalent values in the Cartesian coordinate system (complex plane), with the axes representing the real component and the imaginary component. As illustrated in FIG. 5, if the rails are in a normal state, when no train is present on the rails, the location of the plot point coincides with the location P1. When a rail breakage occurs, the location of the plot point changes largely from the location P1. More specifically, the real component of the impedance equivalent value is maintained at a positive value, but the imaginary component is changed to a negative value. As a result, the location of the plot point transits from the first quadrant to the fourth quadrant. As the rail breakage is positioned nearer the transmission point of the AC signal, both the real component and imaginary component of the impedance equivalent value become larger. As a result, the location of the plot point transits to a location P4, which is apart from the origin O. FIG. 5 illustrates locations P4-1 and P4-2 of the plot points of the impedance equivalent values in a case of a rail breakage at different locations. When the plot point coincides with the location P4-1, the location of a rail breakage is nearer to the transmission point than when the location of a rail breakage coincides with the location P4-2.

[0052] When a rail breakage occurs, the location P4 of the plot point of the impedance equivalent value in the Cartesian coordinate system (complex plane) depends on the location of the rail breakage. Therefore, by determining in advance the relationship between a location of a rail break and the location P4 of the plot point of the impedance equivalent value, for example, through measurement or calculation, the determination section 35 can determine the location of a rail breakage from the location P4 of the plot point.

[0053] As described above, when a rail breakage occurs, the plot point of the impedance equivalent value is positioned at a location P4, which deviates from the reference trajectory. However, as illustrated in FIG. 6, after the train has run beyond the location of the rail breakage, the location of the plot point of the impedance equivalent value changes along the reference trajectory because the rails are shorted by the axle of the train at a location nearer to the transmission point than the location of the rail breakage. Therefore, after the plot point has deviated from the reference trajectory, when the location of the plot point returns to the reference trajectory and then changes along the reference trajectory, the determination section 35 can determine that the location at which the plot point returns to the reference trajectory is the location of the rail breakage.

(B) Abnormality related to leakage conductance

[0054] FIG. 7 is a diagram illustrating an example of the plot point of impedance equivalent value in the case of an abnormality related to leakage conductance. For clarity, the change (trajectory) in the plot point of the impedance equivalent value in the case of an abnormality related to leakage conductance across the entire rail area is illustrated with the bold line. The abnormality related to the leakage conductance refers to a change in the leakage conductance components G (= 1/Rb) in the equivalent circuit of the track circuit illustrated in FIGs. 2A, 2, and 2C. The abnormality related to the leakage conductance mainly refers to an increase in the leakage conductance due to poor insulation between each rail and the ground, which may be caused by moisture in rain and snow, for example.

[0055] If an abnormality related to leakage conductance occurs, the impedance of the track circuit changes when the train runs (passes) through the detection segment T1. As a result, the plot point of the impedance equivalent value in the Cartesian coordinate system (complex plane) deviates from the reference trajectory. For example, as the leakage conductance components G (= 1/Rb) increase, the impedance equivalent value decreases because the impedance of the track circuit decreases. As a result, the plot point in the Cartesian coordinate system (complex plane) becomes shorter than the reference trajectory. FIG. 6 illustrates that leakage conductance is increasing throughout the rails; the change in the location of the plot point of the impedance equivalent value with the passing of the train draws a trajectory shorter than the reference trajectory, as indicated by the bold line. However, even if an abnormality related to leakage conductance occurs, the location of the plot point changes toward the origin O of the Cartesian coordinate system with the running of the train, as in the case of the normal state.

[0056] As the leakage conductance becomes larger, the trajectory of the plot point becomes shorter than the reference trajectory. In this case, the location P1 of the plot point when the train is not present on the rails (when no train is present in the detectable range) is positioned nearer the location P2 of the plot point when the train enters the detection segment T1. Therefore, when the plot point is positioned near the location P2 on the reference trajectory, it is difficult to distinguish whether the reason why this plot point is positioned at the location P1 near the location P2 is that no train is present on the rails but the leakage conductance has increased or that no abnormality related to leakage conductance occurs but the train has entered the detection segment T1. Consequently, it is difficult to determine whether the train is present or absent on the rails. In particular, it is difficult to determine the change in the plot point from the location P1 at which no train is present on the rails to the location P2 at which the train enters the detection segment T1.

[0057] In the present exemplary embodiment, the leakage conductance of the track circuit is simply a circuit element in the track circuit. When the train is present at the transmission point on the rail, the impedance as viewed from the transmission point is formed of the axle-shorting impedance Rv alone, as illustrated in FIGs. 2A, 2B, and 2C. In this case, the impedance is substantially unchanged. Therefore, when the plot point is positioned at the location P1 near the location P2 on the reference trajectory, the track circuit apparatus 1 can distinguish whether the train is not present on the rail but the leakage conductance has increased or no abnormality related to leakage conductance occurs but the train has entered the detection segment T1, based on a detection result of another track circuit apparatus which indicates whether the train is present or absent in another detection segment adjacent to the detection segment T1. In this way, it is possible to determine whether an abnormality related to leakage conductance has occurred.

[0058] As illustrated in FIG. 8, another track circuit apparatus 1B is installed so as to cover a detection segment T2, which is disposed adjacent to the entry side (the entry side in the running direction) of the detection segment T1 . As described above, the track circuit in the present embodiment is an uninsulated track circuit. Thus, when being transmitted from the transmission point to the rail, the AC signal also propagates to another segment adjacent to the exit side (on the exit side in the running direction) of the detection segment. For this reason, in FIG. 8, the detection segment for the track circuit apparatuses includes two segments arranged in a row in front of and in back of each transmission point. More specifically, the track circuit apparatus 1 covers, as the detection segment T 1, two detection segments T1a and T1b in front of and in back of a transmission point thereof (location L3), whereas the track circuit apparatus 1B covers, as the detection segment T2, two detection segments T2a and T2b in front of and in back of a transmission point thereof (location L1). The level of the AC signal to be transmitted by the track circuit apparatus 1 to the transmission point (location L3) is designed so that the detectable range contains the transmission point (location L1) of the track circuit apparatus 1B.

[0059] In the above case, when a train is present on the rails at the transmission point (location L1) of the track circuit apparatus 1B, the track circuit apparatus 1B can determine that the train is present at the transmission point (location L1), based on the magnitude of the impedance as viewed from the transmission point (location L1). Then, the track circuit apparatus 1 can determine whether an abnormality related to leakage conductance has occurred by comparing the magnitude of the impedance as viewed from the transmission point (location L3) at that time with the magnitude of the impedance in the normal state (where no abnormality related to leakage conductance has occurred). In this case, when the leakage conductance increases, the magnitude of the impedance decreases.

[0060] When an abnormality related to leakage conductance occurs not in the entire rails but in a portion of the rails, the track circuit apparatus 1 can determine the location of the abnormality related to leakage conductance, from the change in the location of the plot point of the impedance equivalent value with the running of the train. Thus, when an abnormality related to leakage conductance occurs, the plot point of an impedance equivalent value is positioned at a location deviating from the reference trajectory, as in the case of a rail breakage. However, after the train has passed through the location of the abnormality related to leakage conductance, the rail is shorted by the axle of the train at a location closer to the transmission point than the abnormal location. Therefore, the location of the plot point of the impedance equivalent value changes along the reference trajectory. Thus, after a plot point has deviated from the reference trajectory, when a plot point returns to the reference trajectory and then changes along the reference trajectory, the track circuit apparatus 1 can determine that the location at which the plot point has returned to the reference trajectory is the location of an abnormality related to leakage conductance.

(C) Tolerance fluctuation range

[0061] The determination section 35 determines a state of the rails (whether the rails are normal or not) by comparing the location of the plot point of the impedance equivalent value in the Cartesian coordinate system (complex plane) with the reference trajectory. Actually, however, the location of the plot point of the impedance equivalent value is not always positioned perfectly on the reference trajectory even when the rail is in a normal state. The main reason is that, since the rails are installed outdoors, the leakage conductance and capacitance components between the rails are slightly fluctuated by the influence of temperature, humidity, rainfall, or snowfall, for example. For this reason, as illustrated in FIG. 9, a tolerance fluctuation range, which is an allowable range of fluctuations of the impedance equivalent value at the location P1 on the reference trajectory, is defined for the reference trajectory. FIG. 9 illustrates the tolerance fluctuation range for the location P1; the tolerance fluctuation range for the location P1 corresponds to the area indicated by the dashed line surrounding the location P1. If the location of the plot point of an impedance equivalent value is outside this tolerance range, the track circuit apparatus 1 determines that some abnormality has occurred or an indication of the abnormality has appeared. Examples of such abnormalities or indications include a rail breakage or an abnormality related to leakage conductance, as described above.

[Transmission of AC signal]

[0062] Next, how to transmit an AC signal will be described. In the present embodiment, the processing apparatus 30 transmits an AC signal interruptedly (intermittently). This interrupted transmission of the AC signal is achieved by controlling the transmission voltage with the transmission voltage output section 36.

[0063] During an idle period in which the AC signal is not transmitted, the transmission voltage and frequency setting section 37 turns off the transmission switch of the transmitter 10 or halts the output thereof, whereas the noise measurement section 39 measures noise (return noise) of the rails. Then, the set frequency and transmission level determination section 38 performs a frequency analysis process, such as a fast Fourier transformation (FFT) process, on the noise (return noise) measured by the noise measurement section 39, thereby determining the level and frequency of the noise (return noise). After that, the set frequency and transmission level determination section 38 sets the set frequency and set transmission level of the AC signal to a frequency and level that do not interfere with noise (return noise).

[0064] By transmitting the AC signals interruptedly (intermittently), the transmission power can be reduced, so that the track circuit apparatus 1 can save even more energy. Furthermore, the AC signal is transmitted at an optimal transmission level according to noise levels (return noise) of the rails, so that the track circuit apparatus 1 can further save energy. The track circuit apparatus 1 can also transmit an AC signal to the rails at an optimal frequency that does not interfere with frequencies other than that of the return noise of the rails, so that the AC signal does not affect other signals flowing through the rails.

[Function and effect]

[0065] According to the present embodiment, it is possible to realize a track circuit apparatus 1 that is quite different in principle from conventional track circuit apparatuses. More specifically, the impedance of the track circuit as viewed from the transmission point of the AC signal changes depending on whether a train is present or absent on the rails. With this impedance change, the amplitudes of and phase difference between the transmission voltage and the transmission current are varied. Therefore, the impedance equivalent value of the track circuit can be determined from the amplitudes of and phase difference between the transmission voltage and the transmission current. Then, the presence of a train on the rails can be determined based on the real component (resistance component) and imaginary component (reactance component), both of which express the impedance equivalent value with complex numbers. Since the presence of a train can be determined based on the transmission voltage and transmission current of the AC signal transmitted to the rails, no receiver is necessary, and there is no need to transmit a signal with a constant signal level at the reception point, thereby successfully reducing the transmission power. As a result, it is possible to realize an energy-saving track circuit apparatus 1. Moreover, since no receiver is necessary, it is possible to provide a further effect in which the number of components can be made smaller than that of conventional track circuit apparatuses.

[Modifications]

[0066] Exemplary embodiments to which the present disclosure is applicable are not limited to the foregoing exemplary embodiment and can be modified as appropriate without deviating from the spirit of the present disclosure.

(A) Scanning system

[0067] In the foregoing exemplary embodiment, the track circuit apparatus 1 transmits an AC signal to a single detection segment T1; however, the track circuit apparatus 1 may also sequentially transmit an AC signal to a plurality of detection segments in a switching manner, in other words, may employ a so-called scanning system.

[0068] FIG. 10 is a diagram illustrating an example of a scanning type of track circuit apparatus. As illustrated in FIG. 10, a scanning type of track circuit apparatus 1A further includes a switching switch group 18, which is a set of switching switches through which an AC signal is to be transmitted to each of transmission points in a plurality of detection segments T1, T2, and so on. A processing apparatus 30A outputs, to the switching switch group 18, a switching signal for use in selecting one of the switching switches which is related to a detection segment (one of the detection segments T1, T2, and so on) to which the AC signal is to be transmitted and controlling the turn-on of this switching switch. Then, the AC signal is transmitted to the selected detection segment. In FIG. 10, two segments in front of and in back of a transmission point, which is the boundary of a track circuit, are used as one detection segment. The level of the AC signal to be transmitted to the transmission point is expected to be designed so that the transmittable range for one detection segment contains the transmission points of adjacent detection segments. It is thereby possible to selectively switch between the detection segments to which the AC signal is to be transmitted while tracking a train, with the exception of the entry-side detection segment of the track circuit apparatus 1A. In this case, the frequency of the AC signal to be transmitted may be switched in accordance with the detection segments T1, T2, and so on.

(B) Insulated track circuit

[0069] The exemplary embodiment has been described in the case where the track circuit is an uninsulated track circuit; however, the track circuit may also be an insulated track circuit. FIG. 11, which corresponds to FIG. 4, is a diagram illustrating an example of the trajectory of the plot points of impedance equivalent values of the track circuit in the Cartesian coordinate system (complex plane) in the case where a detection segment T1 illustrated in FIG. 1 is an insulated track circuit. In the case of the insulated track circuit, the AC signal flows only through the detection segment T1 and does not flow through adjacent segments accordingly. Thus, as illustrated in FIG. 11, the plot point is maintained at a location P1 until a train has entered a detection segment T1. Immediately after the train has entered the detection segment T1 (on-rail location L2), the location of the plot point transits to a location P2. After that, as in the case of the uninsulated track circuit, the location of the plot point changes in an analog fashion from the location P2 to a location P3 (origin O) with the running of the train. When the train enters (arrives at) the transmission point, the location of the plot point transits to a location P3 (origin O). Immediately after the train has exited from (passed through) the transmission point and exits from the detection segment T1, the location of the plot point transitions to the location P1.

[0070] It should be noted that the detection segment T1 may be formed of two segments arranged in a row in front of and in back of the transmission point. In this case, after the train has exited from (passed through) the transmission point, the location of the plot point of the impedance equivalent value changes from the location P3 (origin O) so as to gradually return to the location P2 in the reverse order of the previous one. Immediately after the train has exited from the detection segment T1, the location of the plot point transits to the location P1.

(C) Poor insulation at boundary of insulated track circuit

[0071] If the track circuit is an insulated track circuit, poor insulation at the boundary of the track circuit can be further determined as a state of the rails. Poor insulation at the boundary of the track circuit may be caused by foreign matter deposited on an insulating material or deterioration of the insulating material.

(D) Trajectory drawn by multiple train passages

[0072] The trajectories of impedance equivalent values generated by multiple train passages may be acquired and collected. Then, the trajectories drawn by these passages may be compared together to determine an abnormality on the rails or an indication of the abnormality. Alternatively, an abnormality on the rails or an indication of the abnormality may be determined by comparing the trajectory drawn by a single train passage with the reference trajectory. The comparison of the trajectories drawn by multiple passages and the comparison between a single trajectory and the reference trajectory can be made, for example, based on the similarity calculated by pattern matching, in which each or the trajectory is regarded as an image, or based on whether an error rate calculated by the least-squares method, for example, satisfies a predetermined threshold condition. Furthermore, data regarding the reference trajectory stored by a determination section 35 may be updated based on the change in the locations of plot points when the state of the rails is considered to be normal.

[REFERENCE SIGNS LIST]

[0073]

1 track circuit apparatus
10 transmitter
20 current sensor
30 processing apparatus
31 transmission voltage waveform acquisition section
32 transmission current waveform acquisition section
33 quadrature detection circuit section
34 impedance equivalent value calculation section
35 determination section
36 transmission voltage output section
37 transmission voltage and frequency setting section
38 set frequency and transmission level determination section
39 noise measurement section

Claims

1. A track circuit apparatus comprising:

a calculation section that calculates an impedance equivalent value, based on amplitudes of a transmission voltage and a transmission current of an alternating current signal transmitted from a transmission section to a rail and a phase difference between the transmission voltage and the transmission current; and
a determination section that determines presence of a train on the rail, based on values of a real component and an imaginary component of the impedance equivalent value.

2. The track circuit apparatus as defined in claim 1, wherein the determination section determines a location of the train present on the rail relative to a transmission point of the alternating current signal from the transmission section.

3. The track circuit apparatus as defined in claim 2, wherein the determination section determines the location of the train present on the rail relative to the transmission point, based on a plot point of the impedance equivalent value in a coordinate system with axes representing the real component and the imaginary component.

4. The track circuit apparatus as defined in claim 3, wherein the determination section determines the location of the train present on the rail, based on a location of the plot point along a predetermined reference trajectory in the coordinate system.

5. The track circuit apparatus as defined in any one of claims 1 to 4, wherein the determination section determines a state of the rail, based on the values of the real component and the imaginary component of the impedance equivalent value.

6. The track circuit apparatus as defined in claim 5, wherein the determination section determines a location of an abnormality on the rail relative to the transmission point of the alternating current signal from the transmission section.

7. The track circuit apparatus as defined in claim 4, wherein, when the plot point deviates from the reference trajectory, the determination section determines a location of an abnormality on the rail related to leakage conductance and/or a rail breakage, based on the deviating location.

8. The track circuit apparatus as defined in any one of claims 1 to 7, wherein the determination section determines whether a rail breakage has occurred, based on a sign of a value of the imaginary component.

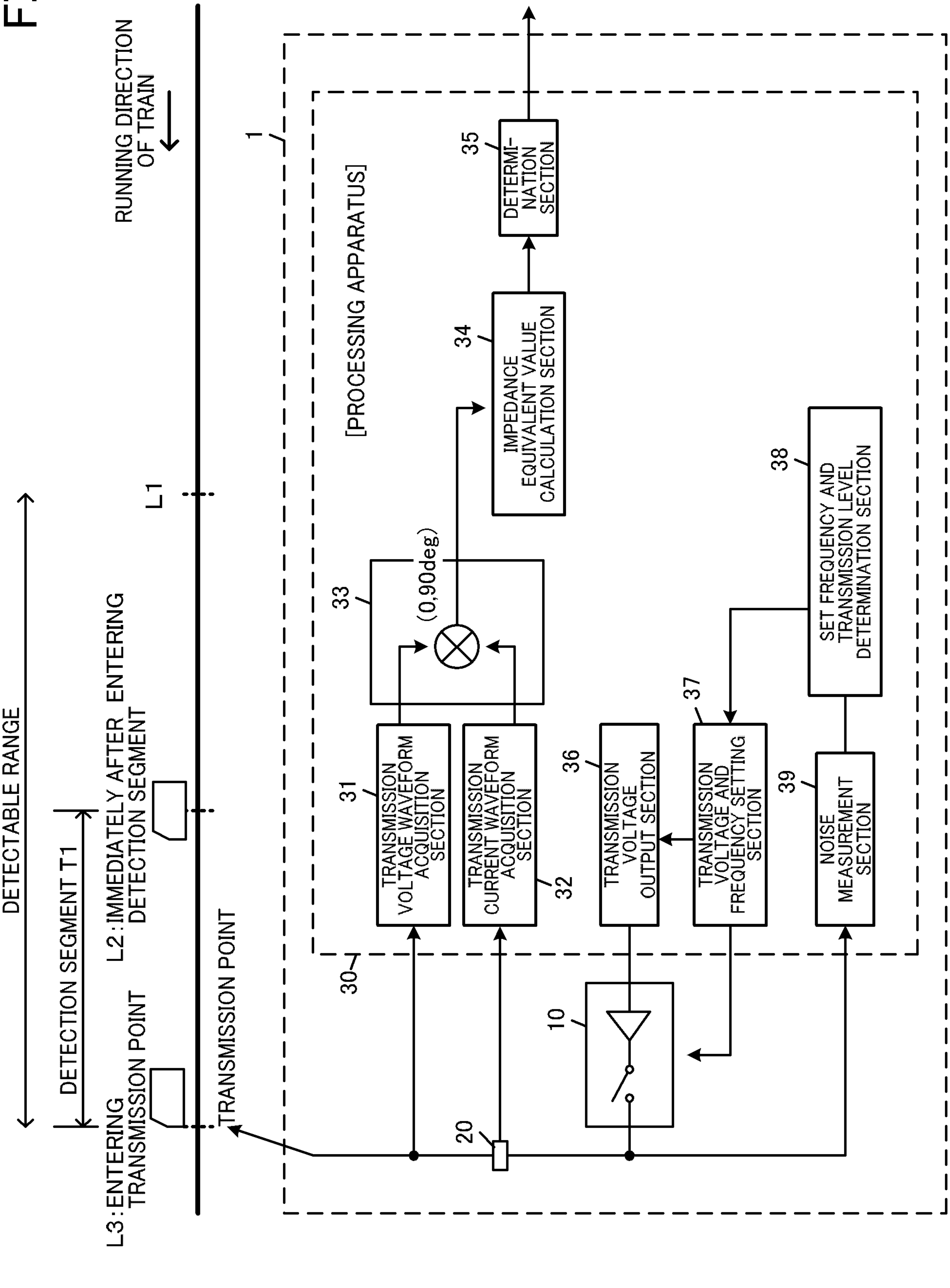
9. The track circuit apparatus as defined in claim 8, wherein the determination section determines a location of the rail breakage relative to the transmission point of the alternating current signal from the transmission section, based on the values of the real component and the imaginary component of the impedance equivalent value.

10. The track circuit apparatus as defined in any one of claims 1 to 9, wherein the determination section determines an abnormality on the rail or an indication of the abnormality, based on whether a plot point of the impedance equivalent value in a coordinate system with axes representing the real component and the imaginary component is outside a tolerance fluctuation range of the impedance equivalent value, the tolerance fluctuation range being defined in accordance with a distance from the transmission point of the alternating current signal from the transmission section.

11. An on-rail train presence determination method comprising:

measuring a transmission voltage and a transmission current of an alternating current signal transmitted from a transmission section to a rail;
calculating an impedance equivalent value, based on amplitudes of the transmission voltage and the transmission current and a phase difference between the transmission voltage and the transmission current; and
determining presence of a train on the rail, based on values of the real component and the imaginary component of the impedance equivalent value.

FIG.1



DETECTABLE RANGE
DETECTION SEGMENT T1
L3: ENTERING TRANSMISSION POINT
L2: IMMEDIATELY AFTER ENTERING DETECTION SEGMENT
TRANSMISSION POINT
L1
RUNNING DIRECTION OF TRAIN
1
[PROCESSING APPARATUS]
30
31
TRANSMISSION VOLTAGE WAVEFORM ACQUISITION SECTION
32
TRANSMISSION CURRENT WAVEFORM ACQUISITION SECTION
33
(0,90deg)
34
IMPEDANCE EQUIVALENT VALUE CALCULATION SECTION
35
DETERMI-NATION SECTION
36
TRANSMISSION VOLTAGE OUTPUT SECTION
37
TRANSMISSION VOLTAGE AND FREQUENCY SETTING SECTION
38
SET FREQUENCY AND TRANSMISSION LEVEL DETERMINATION SECTION
39
NOISE MEASUREMENT SECTION
10
20

FIG.2A

TIME OF ABSENCE OF TRAIN

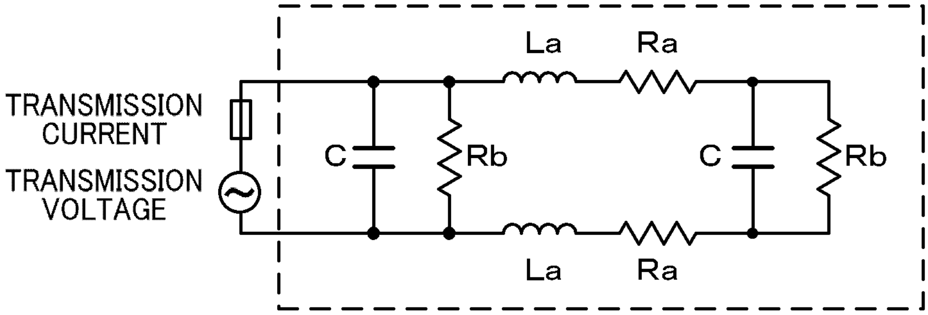


FIG.2B

IMMEDIATELY AFTER ENTERING DETECTION SEGMENT (ON-RAIL LOCATION L2)

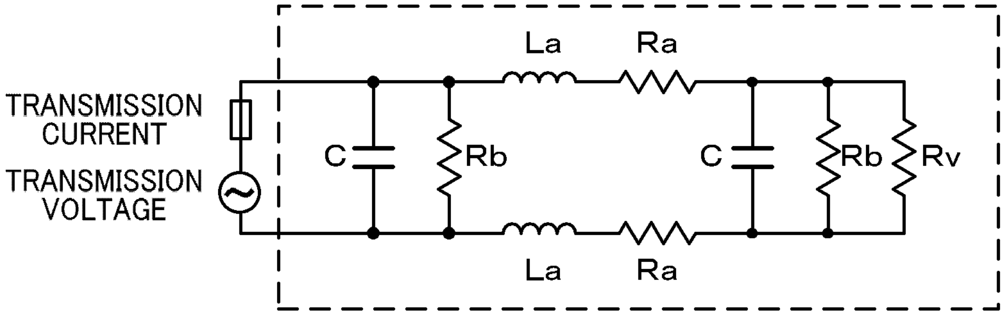


FIG.2C

TIME OF ENTERING TRANSMISSION POINT (ON-RAIL LOCATION L3)

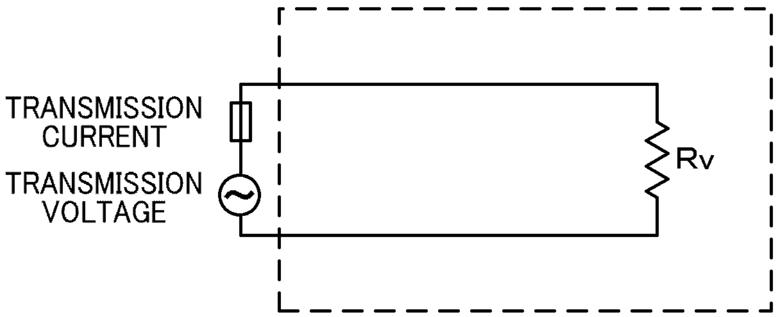


FIG.3

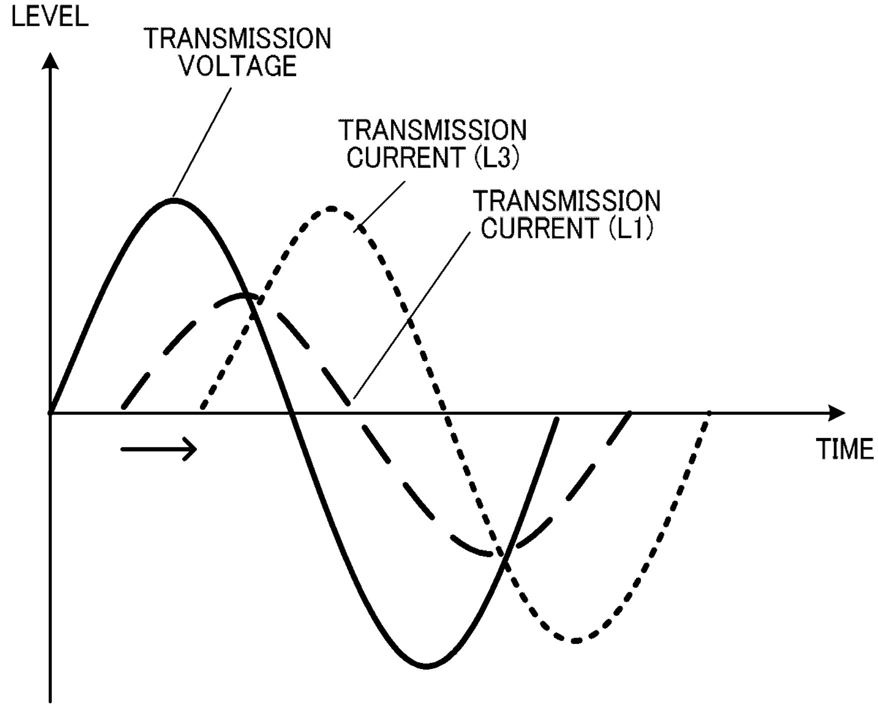


FIG.4

[TRAJECTORY OF IMPEDANCE EQUIVALENT VALUE
(CASE OF UNINSULATED TRACK CIRCUIT)]

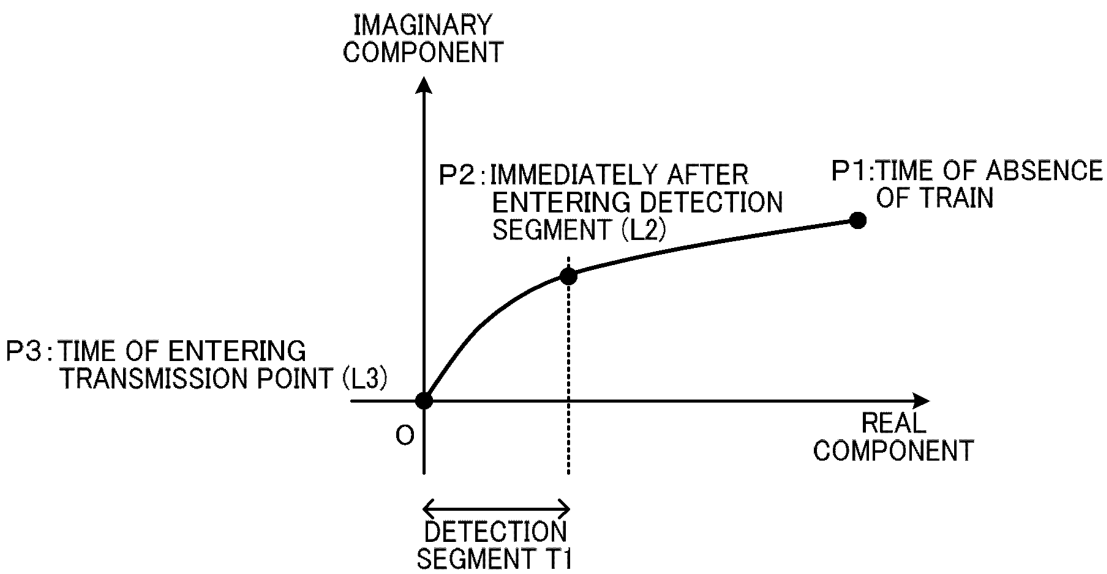


FIG.5

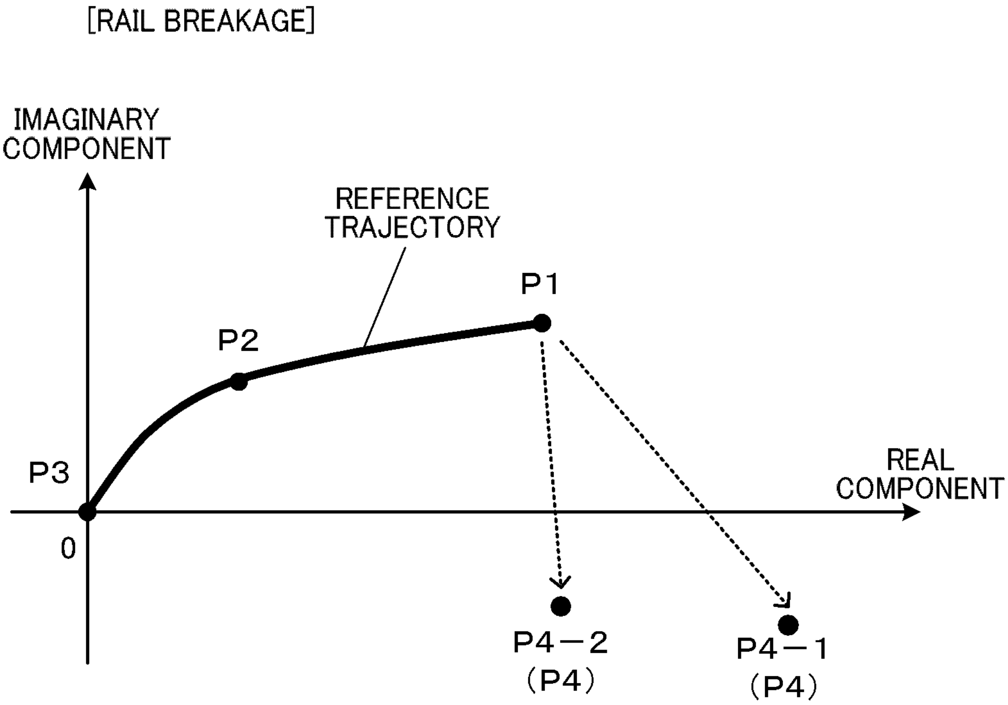

[RAIL BREAKAGE]
IMAGINARY COMPONENT
REFERENCE TRAJECTORY
P1
P2
P3
0
REAL COMPONENT
P4－2
(P4)
P4－1
(P4)

FIG.6

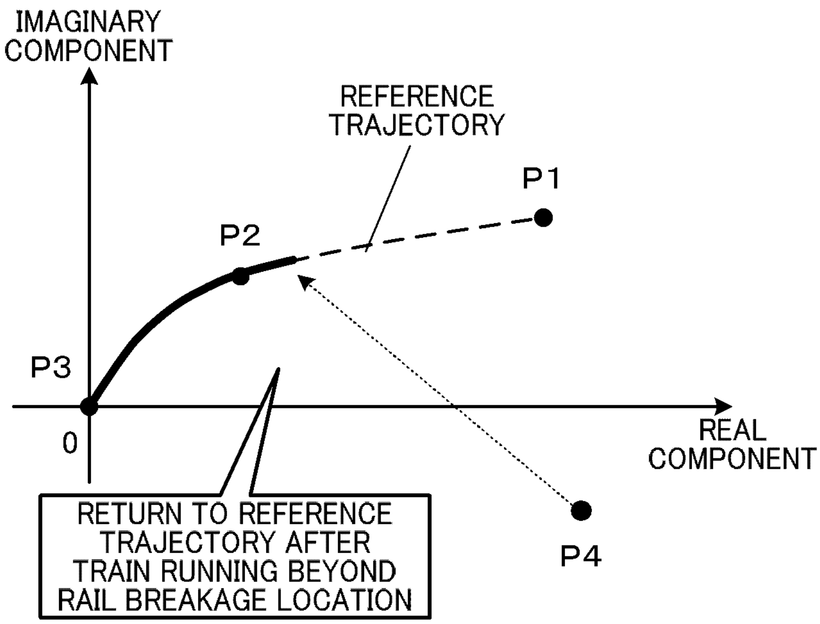

IMAGINARY COMPONENT
REFERENCE TRAJECTORY
P1
P2
P3
0
REAL COMPONENT
RETURN TO REFERENCE TRAJECTORY AFTER TRAIN RUNNING BEYOND RAIL BREAKAGE LOCATION
P4

FIG.7

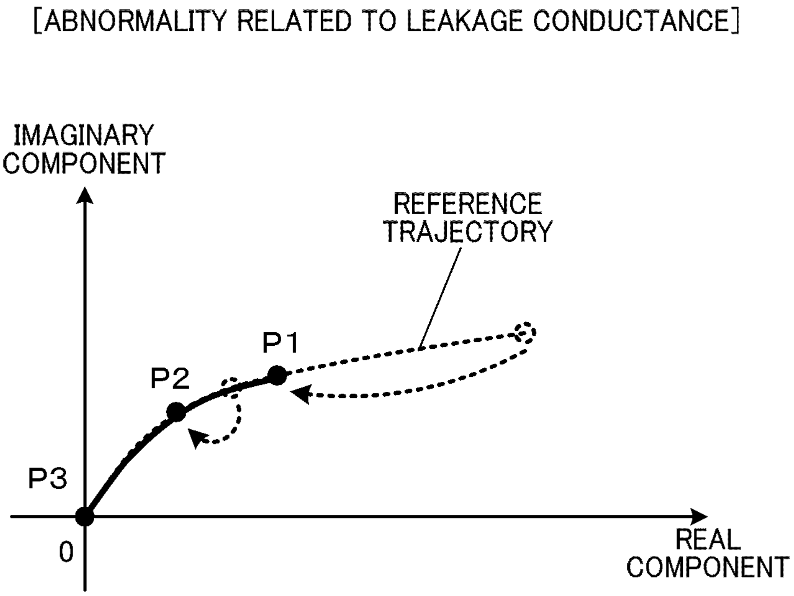

[ABNORMALITY RELATED TO LEAKAGE CONDUCTANCE]
IMAGINARY COMPONENT
REFERENCE TRAJECTORY
P1
P2
P3
0
REAL COMPONENT

FIG.8

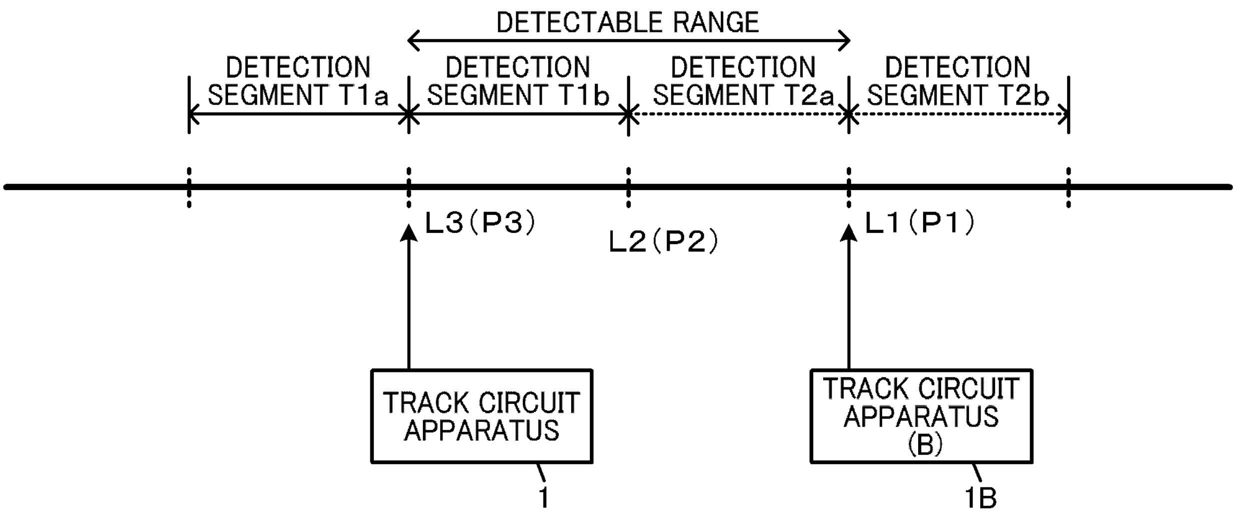

DETECTABLE RANGE
DETECTION SEGMENT T1a
DETECTION SEGMENT T1b
DETECTION SEGMENT T2a
DETECTION SEGMENT T2b
L3(P3)
L2(P2)
L1(P1)
TRACK CIRCUIT APPARATUS
TRACK CIRCUIT APPARATUS (B)
1
1B

FIG9

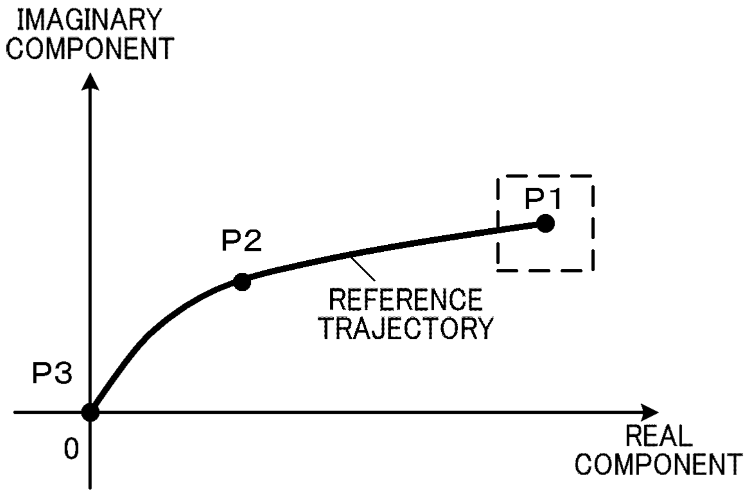

IMAGINARY
COMPONENT
P1
P2
REFERENCE
TRAJECTORY
P3
0
REAL
COMPONENT

FIG.10

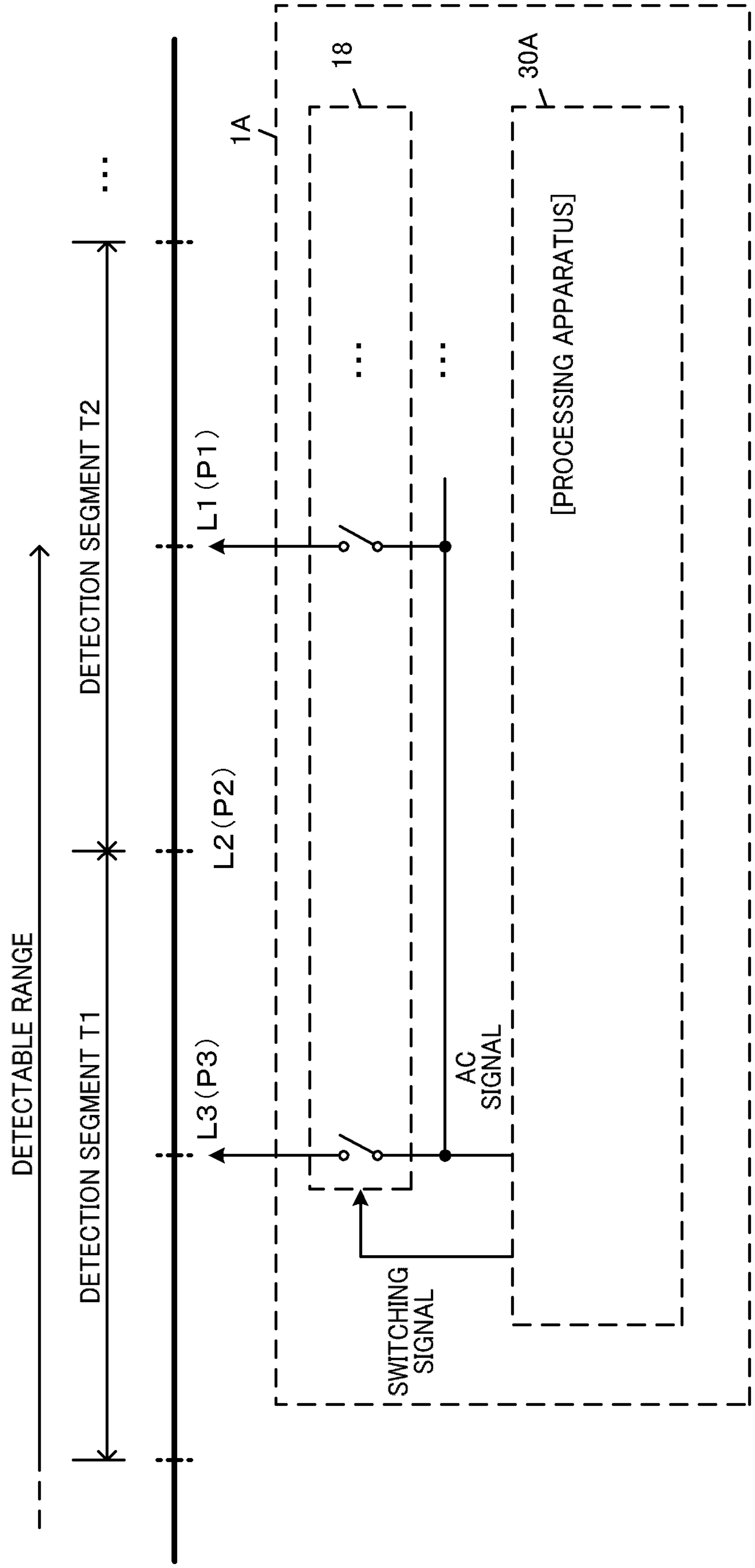
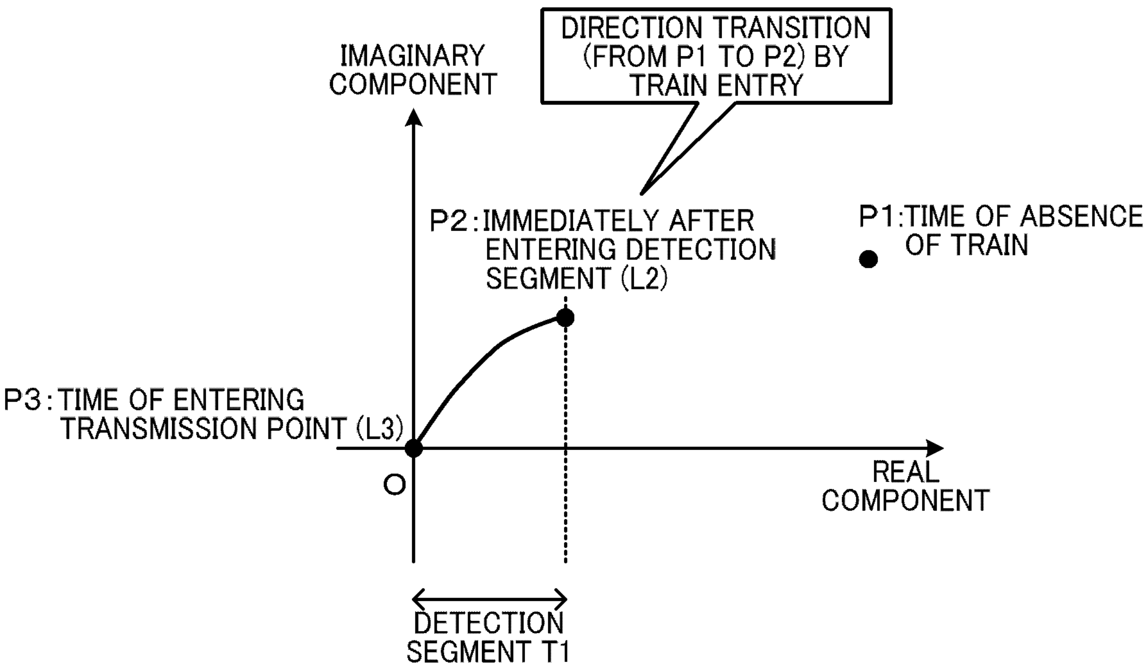

DETECTABLE RANGE
DETECTION SEGMENT T2
DETECTION SEGMENT T1
L1(P1)
L2(P2)
L3(P3)
1A
18
30A
[PROCESSING APPARATUS]
AC SIGNAL
SWITCHING SIGNAL

FIG.11

[TRAJECTORY OF IMPEDANCE EQUIVALENT VALUE
(CASE OF INSULATED TRACK CIRCUIT)]



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/015744

A. CLASSIFICATION OF SUBJECT MATTER

B61L 1/18(2006.01)i
FI: B61L1/18 H

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B61L1/18

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2021-100831 A (NIPPON SIGNAL CO LTD) 08 July 2021 (2021-07-08) entire text, all drawings	1-11
A	JP 2011-207453 A (DAIDO SIGNAL CO LTD) 20 October 2011 (2011-10-20) entire text, all drawings	1-11

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 July 2023	**18 July 2023**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/015744

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2021-100831 A	08 July 2021	(Family: none)	
JP 2011-207453 A	20 October 2011	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2021113023 A **[0003]**